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NOTES

ON

NATURAL PHILOSOPHY

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NOTES

OF A COURSE OF NINETEEN LECTURES ON

NATURAL PHILOSOPHY

DELIVERED AT GUY'S HOSPITAL DURING
THE SESSION 1872–73

BY

eorge arrer
G. F. RODWELL, F.R.A.S. F.C.S.

LECTURER ON NATURAL PHILOSOPHY IN GUY'S HOSPITAL,
SCIENCE MASTER IN MARLBOROUGH COLLEGE.

LONDON
J. & A. CHURCHILL, NEW BURLINGTON STREET
1873

Veritas autem non a felicitate temporis alicujus, quæ res varia est; sed a lumine Naturæ et experientiæ, quod eternum est, petenda est.—BACON, *Novum Organum.*

PREFACE.

THE following Notes were written for the use of the Students who attended my Lectures at Guy's Hospital during the last Session. It was afterwards thought that they might be found useful elsewhere, hence their appearance in the present form. The subject-matter has been somewhat enlarged, and the order in which the subjects occurred has been changed, as it was considered advisable to commence the Course with one of the more experimental sciences; but in the main, the Notes are precisely the same as those with which we worked. The omission of Acoustics, and the comparatively slight treatment which the subject of Light has received, is to be accounted for by the fact that the Lectures had special reference to the requirements of the "Preliminary Scientific" (M.B.) examination of the University of London. It is hoped that the various definitions—incomplete as some of them must necessarily be—may prove serviceable in directing the study of those who wish to acquire a knowledge of some of the principal laws of Nature; while

Heller, Gift 6-30-17

the experimental hints may perhaps induce the reader to prepare, and try for himself, various experiments, of which only a faint idea can be obtained from simple description. Those who may desire to use the Notes for lecture purposes will recognise at once that the main difficulty has been to condense the matter sufficiently; hence, by enlarging individual notes, or by fully illustrating those given, they can readily increase the number of lectures to any extent they please; and I shall be glad if they find this framework useful for the erection of their greater structures.

G. F. RODWELL.

MARLBOROUGH, *March* 31*st*, 1873.

CONTENTS.

INTRODUCTION 1

PROPERTIES OF MATTER 3

STATICS 8

DYNAMICS 20

HYDROSTATICS 36

HYDRODYNAMICS 44

PNEUMATICS 60

LIGHT 69

HEAT 82

MAGNETISM 109

STATIC ELECTRICITY 121

DYNAMIC ELECTRICITY 141

CONCLUSION 157

INDEX 161

Partitio enim, quæ fit sola cogitatione, nihil mutat; sed omnis materiæ variatio, sive omnium ejus formarum diversitas, pendet à motu.—DESCARTES, *Principia*, pars 2.

DIVISION OF THE SUBJECT-MATTER INTO LECTURES.

LECTURE I.

STATICS.

Introduction—Definition of Natural Philosophy—Experiment necessary because the Senses are fallacious—Matter—Its Properties—General and Special—Extension—Impenetrability—Divisibility—Porosity—Compressibility—Inertia—Cohesion—Tenacity—Malleability—Ductility—Elasticity—Definition of Mechanical Philosophy—Mass—Weight—Force—Direction, and Magnitude of a Force—Composition of Forces—Resolution of Forces—Parallelogram of Forces . . . . . Pages 1-10

LECTURE II.

STATICS.

Definition of a *Machine*—Power and Resistance—The Mechanical Powers—The Three Forms of Lever—Examples—Principle of *Moments*—Conditions of Equilibrium—The Wheel and Axle—The Inclined Plane—The Wedge—The Screw—The Pulley—Gravity—The Centre of Gravity—Experimental Illustration of Statics 11-19

LECTURE III.

DYNAMICS.

Definition of Dynamics—Units of Length, Surface, Volume, Time, Velocity—Line of Motion—Uniform Velocity—Variable Velocity—Mean Velocity—Uniformly accelerated, and retarded Velocity—Momentum—Unit of Force—Unit of Mechanical Work—The Laws of Motion—Composition of Velocities—Newton's Law of Universal Gravitation Pages 20-25

LECTURE IV.

DYNAMICS.

Laws of Falling Bodies—Variation in the Accelerating Force of Gravity—Projectiles—The Pendulum—Centre of Oscillation—Energy—Potential and Kinetic Energy of a Pendulum—Energy of a Body falling down an Inclined Plane—Angular Velocity—Energy of a Body moving in an Ellipse—Impact of Inelastic Bodies—Experimental Illustration of Dynamics 26-35

LECTURE V.

HYDROSTATICS.

Definition of Hydrostatics—Differences between Liquids and Solids—Capillarity—Slight Compressibility of Liquids—Liquids transmit Pressures equally in all Directions—The Hydrostatic Press—Liquids exert Pressures proportional to their Densities—Upward Pressure of Liquids—Buoyancy—The Law of Archimedes—The Specific Gravity of Bodies—Experimental Illustration of Hydrostatics . 36-43

LECTURE VI.

HYDRAULICS OR HYDRODYNAMICS.

Definition of the Science—Torricelli's Law—Conditions upon which the Efflux of Liquids depends—The *Vena Contracta*—Nature of a descending Jet—Lateral Action—Water considered as a Motive Power—The Screw of Archimedes—Account of Experiments on the Constitution of a Descending Liquid Jet—Experimental Illustration of Hydrodynamics . . . . . Pages 44-59

LECTURE VII.

PNEUMATICS.

Definition of the Science—Nature of Gases—Weight of the Air—The Barometer—The Torricellian Vacuum—Pascal's Law applied to Gases—Elasticity of Gases—Boyle's Law—The Law of Archimedes applied to Gases—The Air-pump—The Water-pump—The Siphon—Experimental Illustration of Pneumatics 60-68

LECTURE VIII.

LIGHT.

Significance of the term *Light*—The Undulatory Theory—The Interstellar Medium—Rectilinear Propagation of Light—Undulations—Luminous Bodies—Illuminated Bodies—Transparent and Opaque Bodies—Law of Inverse Squares—Velocity of Light—Reflection of Light—Mirrors—Principal and Virtual Focus—Refraction of Light—Descartes' Law of Sines—Index of Refraction—Lenses—Prisms—Dispersion

of Light—The Solar Spectrum—The Camera Obscura—The Eye—Adjustment to different Distances—Experimental Illustration of Light . . . Pages 69-81

LECTURE IX.

HEAT.

Definition of the Science—Early Ideas relative to the Nature of Heat — Determination of the Mechanical Equivalent — Sources of Heat—Conversion of Kinetic Energy into Heat—Production of Heat by Chemical Action, and by Electricity in Motion—Consumption of Heat in the Performance of Mechanical Work 82-86

LECTURE X.

HEAT.

Heat determines the Form in which Matter exists—The Solid, Liquid, and Gaseous Conditions — Expansion of Solids, Liquids, and Gases—Co-efficient of Expansion—Thermometers—Evaporation—Ebullition—Evaporation in the Spheroidal Condition 87-93

LECTURE XI.

HEAT.

Solidification — Crystallisation — Anomalous Behaviour of Water in solidifying—Maximum Density of Water—Internal Work of a Mass of Matter—Molecular Potential Energy —Latent Heat—Specific Heat—Conduction of Heat—Convection of Heat 94-98

LECTURE XII.

HEAT.

Radiant Heat—Definition—Connection between Radiant Heat and Light—The Heat Spectrum—Prevost's Theory of Exchanges—Reflection of Heat—Refraction of Heat—Dew—Dew-point—Absorption of Heat—Radiation of Heat—Radiation from the Sun—Maintenance of the Sun's Heat—Experimental Illustration of Heat . Pages 99-108

LECTURE XIII.

MAGNETISM.

Natural Magnet—Artificial Magnet—Magnetisation—Condition of a Magnetised Steel Bar—Magnetic Poles and Equator—Magnetic Attraction and Repulsion—Hypothesis of Magnetic Fluids—Polarity—Soft Iron and Steel—Coercive Force—Induction—Definition—Magnetic Metals—Influence of Heat on Magnetism 109-114

LECTURE XIV.

MAGNETISM.

Terrestrial Magnetism—Magnetic Meridian—Magnetic Declination; Secular, Annual, Daily—Isogonal Lines—Inclination or Dip—Isoclinic Lines—Magnetic Equator and Poles of the Earth—Variations in the Intensity of the Earth's Magnetism—Diamagnetism—Universality of Magnetic Action—Experimental Illustration of Magnetism . . 115-120

LECTURE XV.

STATIC ELECTRICITY.

Early Knowledge of the Subject—Production of Electricity by Heat, and Chemical Action—Conversion of Kinetic Energy into Electricity—Conductors and Non-Conductors—Positive and Negative Electricities—Electroscopes—Hypothesis of two Fluids—Distribution of Electricity on the Surface of Bodies—Action of Points—Dissipation of Electricity—Convection of Electricity . . . Pages 121-126

LECTURE XVI.

STATIC ELECTRICITY.

Electrical Induction — Dissimulated Electricity — Faraday's Theory of Induction — Dielectrics — Specific Inductive Capacity—The Electrical Machine—Disruptive Discharge—The Electric Spark 127-132

LECTURE XVII.

STATIC ELECTRICITY.

The Electrophorus—The Leyden Jar: Explanation of its Action—The Electric Shock—Electric Current—Effects produced by Accumulated Electricity—The Return Shock—Atmospheric Electricity—Experimental Illustration of Static Electricity 133-140

LECTURE XVIII.

DYNAMIC OR CURRENT ELECTRICITY.

Definition of the Science—Galvani's Frog Experiment—Theory of Animal Electricity — Volta's Contact Theory—Volta's Pile—Davy's Chemical Theory—Hypothesis of Grotthüss' Electromotive Force — Ohm's Law — Voltaic Batteries — Rationale of Daniell's Battery . Pages 141-148

LECTURE XIX.

DYNAMIC ELECTRICITY.

Comparison of Static with Dynamic Electricity—Quantity and Tension of an Electric Current—Effects produced by a Wire conveying an Electric Current: Physiological, Thermal, Luminous, Chemical, and Magnetic—Electro-negative and Electro-positive Bodies—Oërsted's Discovery of the connection between Electricity and Magnetism—Magnetic Effects of the Current—Solenoids—Mutual Action of Currents—Amperé's Theory of Magnetism — Thermo-Electricity — Experimental Illustration of Dynamic Electricity—Conclusion 149-159

EXPERIMENTAL ILLUSTRATIONS.

THE amount of possible experimental illustration varies considerably with different sciences, as will be seen hereafter. The apparatus needful for the complete illustration of the various laws of Nature and attributes of matter may cost £1500, but much may be done with one-tenth of that amount. If the student of science once clearly masters the principles he desires to prove, he will find that by judicious and minute instruction he can furnish himself with much useful apparatus by employing a good practical carpenter, and a man who can skilfully turn both wood and metal. Better still, if the student can do these things for himself. He is never likely to forget a principle which he has proved by self-made apparatus. Let him never forget to prove a thing experimentally, remembering that a law, coupled with its practical experimental proof, is infinitely more valuable as an inducer of the proper attitude of scientific thought, than fifty laws which are simply remembered without demonstration. Finally, let him strive to attain that *summum bonum* of the Natural Philosopher's life, the enunciation of some law of Nature;—commenced by steady and laborious original experimental research; continued by generalisation and the application of suitable mental processes; ended—*finis coronat opus*—by the development of the law.

NOTES ON NATURAL PHILOSOPHY.

1. THE term *Natural Philosophy* is used in its broadest sense to designate that branch of learning which relates to the external world—the modes, qualities, attributes, internal constitution, external characteristics, of matter, whether living or dead. But in its usual and more restricted sense Natural Philosophy, or Physics (*φύσις*, *Nature*), signifies the knowledge of the properties of bodies, either as masses or molecules, and of the actions which appertain to them, such as their readiness to assimilate or communicate various forms of motion. If matter be changed as to its *composition*, the study of the changes is embraced by the science of Chemistry; if matter be *organised*, that is, if it forms part or has formed part, of an animal or vegetable, the science of Natural History undertakes the investigation of it.

Natura, *nascor*, *γίγνομαι*, to be born, from obsolete *γάω*, to beget, in allusion to Nature as the universal mother. Similarly, *φύσις* may be traced back to *φύω*, to beget. A definition of Nature is difficult; it is sometimes called "the principle which produces all things." Descartes (*Meditatio Sexta*) says:—"Per Naturam enim generaliter spectatam nihil nunc aliud quam vel Deum ipsum, vel rerum creatarum coordinationem à Deo institutam intelligo." And again (*Principia*, pars 2), in allusion to the ideas of the ancient philosophers . . . "dixerunt Naturam esse principium motus et quietis. Tunc enim per Naturam intellexerunt id, per quod res omnes corporeæ tales evadunt quales ipsas esse experimur."

2. In the investigation of Nature we resort to experiment (*experior*, to try, prove); guiding our experimental processes, and examining our experimental results, by means of suitable mental instruments, and apposite modes of thought.

Lord Bacon, the great advocate of the experimental method, at a time when few men beyond Galileo, Kepler, and Gilbert of Colchester, were practising it, tells us that Nature most readily yields up her secrets when she is tortured by experimental means:—"Occulta Naturæ magis se produnt, per vexationes artium quam cum cursu suo meant." Perhaps he had the rack in view when he wrote this, for he had found it efficacious, and we may remember that he was the last English judge to use it.

3. We employ the experimental method because our senses are liable to deceive us. When applied to the investigation of matter external to ourselves, their capabilities of observation are limited. Hence we are obliged to call in the aid of apparatus to exalt the action of the senses in the particular direction desired. Such instances are too numerous to require special mention: the microscope, spectroscope, and galvanometer, are examples.

A simple experiment proves that the senses may sometimes be fallacious. Let three basins be placed in a row; in the left-hand basin pour cold water, in the right-hand basin hot water, and in the middle basin a mixture of equal parts of the hot and cold water. If we now dip one hand into the left-hand basin, and the other into the right-hand basin, and simultaneously remove them and place them in the central basin, the water in it will feel warm to our left hand, and cold to our right hand. Thus the self-same water conveys two distinct and opposite sensations to the brain at the same time. Lord Bacon very justly observes, "Falso cum asseritur, sensum humanum esse mensuram rerum; quin contra, omnes perceptiones, tam sensus quam mentis, sunt ex analogia hominis, non ex analogia universi. Estque intellectus humanus instar speculi inequalis ad radios rerum, qui suam naturam naturæ rerum immiscet, eamque distorquet et inficit."

4. When we investigate Nature, we meet at the outset with two apparently dissimilar entities—the one *matter*, the other *force*. In a rolling stone, the one is the substance of the stone, the other the ~~motion~~ agency which causes it to roll; in a red-hot coal, the one is the substance of the coal, the other the light and heat which it emits. We have to inquire the causes and results of these effects.

PROPERTIES OF MATTER.

5. The term *matter* is used to designate anything which possesses weight (N. 27); or, more strictly (having reference to, and including, that very subtle kind of matter called the ether (N. 170), which we are unable to weigh), we may define it as that which is receptive or communicative of motion. (*Materia*, *mater*, *μητηρ*; Sanskrit, *matri*, a mother, from *ma*, to create: hence, literally, *matter* means *the producer of things.*)

6. Matter possesses various properties cognisable to the senses. The principal of these are *Extension*, *Impenetrability*, *Divisibility*, *Porosity*, *Compressibility*, *Inertia*, and *Cohesion*. These are the more general properties of matter.

7. *Extension* (*extendo*, to stretch out) is the property which matter possesses of occupying space. We can only realise matter which occupies space of three dimensions:—that is, which possesses length, breadth, and thickness.

8. *Impenetrability* is the property which enables matter to occupy space to the exclusion of all other matter—viz. which prevents it from being penetrated by other matter. It is obvious that two bodies cannot occupy the same space at the same time.

9. *Divisibility* (*divido*, to part asunder) is that quality of matter in virtue of which it may be divided into many parts.

10. *Porosity* (πείρω, to pierce through) is the quality possessed by matter which may be expressed by saying that its constituent molecules are separated by vacant spaces.

11. *Compressibility* (*comprimo*, to press together) is the property which enables the molecules of matter to be approximated, and the body which they compose to thus occupy a smaller space. Since matter is impenetrable (N. 8), it is obvious that compressibility is a function of porosity (N. 10).

12. *Inertia* (*iners*, inactive) is a property inherent in matter, whereby it resists change of state. If it be at rest, it cannot acquire motion; if it be in motion, it cannot acquire rest, save from some external source.

13. *Cohesion* (*cohæreo*, to stick together) is an attractive force exercised between similar molecules (N. 202) of matter, acting through an insensible space. It causes molecules to aggregate into sensible masses.

14. The form (solid, liquid, or gaseous) in which any kind of matter exists depends upon the relationship of the cohesion of its molecules to that of its molecular motion or heat. (See Notes 222 to 226.)

15. The cohesion of molecules varies in different substances: and in the same substance the force (like all attractive forces) decreases as the distance between the attracting molecules increases.

16. In virtue of this, different substances present a greater or lesser resistance to fracture; also they suffer themselves with greater or lesser readiness to be beaten out into thin plates, or to be drawn out into fine wire. Again, some bodies resist disintegration more powerfully than others, and on this depends *hardness;* while some offer varying tendencies to recover their original form after having been stretched, compressed, bent, or twisted, and this is *elasticity.* These are the more special properties of matter

17. *Tenacity* (*tenax*, tough; *teneo*, to hold) is the resistance which bodies offer to fracture, that is, to any force tending to tear the particles asunder. One method of determining it is by forming the substances to be tested into rods or wires which have varying weights hung upon them until they break. Thus it has been found that a wire of lead one square millimetre in section breaks with a weight of 4·86 lbs., while wires of zinc, gold, and steel of the same section, require respectively weights of 31·68, 61·60, and 184·36 lbs. to break them.

18. The resistance offered to compression or crushing force is sometimes called *retroactive tenacity.* The following pressures were found to be required to crush cubes 38 millimetres (1½ inch) in the side, of the following substances:—Chalk, 1127 lbs.; fire-brick, 3864 lbs.; cast-iron, 9773 lbs.; Aberdeen granite, 24,580 lbs.

19. *Malleability* (*malleus*, a hammer) is the property which enables certain kinds of matter to be beaten out into thin plates, without rupture. The antithesis to malleability is *brittleness* (Anglo-Saxon, *brytan*, to break). Thus if antimony be hammered it crumbles to powder, while gold may be beaten into leaves $\frac{1}{182,000}$ of an inch in thickness.

20. *Ductility* (*duco*, to draw out) is the property which enables certain kinds of matter to be drawn out into wire, without rupture. Platinum wire has been obtained $\frac{1}{33,000}$ of an inch diameter.

21. *Elasticity* (*ἐλαύνω*, to urge) is the property which enables bodies to recover their original form on the removal of any external force which may have altered their form. Solids possess varying degrees of elasticity, and beyond a certain limit (called the *limit* of *perfect elasticity*) they are either ruptured or disintegrated, or are distorted to such an extent that they cannot regain their original shape. Liquids and gases, on the other hand, are perfectly elastic, and regain their original volume however much they may have been compressed.

22. Elasticity may be evoked in solids by various means. Thus, if a wire be stretched by attaching weights to one end of it while the other end is fixed, it is found that, within the limit of perfect elasticity :— (α) the elongation is proportional to the force applied, and to the length of the wire ; (β) the elongation is inversely proportional to the cross section of the wire, in the case of wires of the same length and substance ; (γ) the wire assumes its original length on the removal of the force.

23. If a wire or rod be twisted, it resists, and if released, within the limits of perfect elasticity, the particles return to their original position. Elasticity has thus been evoked by *torsion* (*torqueo*, to twist). The elasticity of torsion is proportional to the degree of torsion: thus, suppose any particle on the circumference of a cylindrical wire; if the wire be twisted so that the particle moves through 90° of arc, the elastic force tending to bring it back to its original position will be one-half that which it would have been had the particle been moved through 180°.

24. Certain solid bodies, when bent, tend to recover their original position. Elasticity has thus been evoked by *flexure* (*flecto*, to bend). We have numerous examples of this in every form of spring. Springs are sometimes used as measures of force.

STATICS.

25. *Mechanical Philosophy* treats of the laws (α) of forces or pressures in equilibrium, thus of matter at rest; (*Statics*, στάω, ἵστημι, to stand, remain); and (β) of forces which produce motion, thus of matter in motion. (*Dynamics*, δύναμις, force; more correctly *Kinetics*, κινησις, motion.) The sciences which treat of the corresponding conditions in liquids and gases—viz. hydrostatics, hydrodynamics, and pneumatics, also form part of mechanical philosophy.

The term *Mechanical Philosophy* is not much used in the present day. It is occasionally employed to distinguish the conditions of rest and of motion of *masses* of matter, from the actions appertaining to *molecules* of matter, which latter are then classed as *Natural Philosophy* proper.

26. The *mass* of a body is the quantity of matter contained in it (μάσσω, to squeeze together). The *unit of mass* in this country is the pound Avoirdupois, which contains 7000 grains. The unit of mass on the Continent is the mass of one cubic centimetre of water at 4° C. (N. 248); this is called a *gramme*, and is equal to 15·432349 grains.

27. The *weight* of a body is the pressure which it exerts, under the influence of the attraction of the earth, upon another body on which it rests, or to which it is attached. Weight is proportional to mass.

28. Any action which tends to cause a body at rest to move, or a body in motion to change its motion, or to come to rest, is called a *force*.

29. A body is said to be at rest when it continuously occupies the same position.

30. The *direction* of a force is the line in which it tends to cause a body to move.

31. The *magnitude* of a force is the weight it will counterpoise, or pressure it will counteract (N. 27). Different forces may be expressed by different weights compared to some unit of weight, as the pound, gramme (N. 26), or kilogramme (2·2046213 lbs. Avoirdupois).

32. A force may be represented both in magnitude and direction by a straight line. Thus, if we take one pound or one gramme as our unit of weight, and represent it by a line one inch or one centimetre long, then a line four inches or four centimetres long will represent a force of four pounds, or four grammes, as the case may be.

33. If two forces act in the same direction, their effect will be equal to the sum of their magnitudes.

34. If two forces act in contrary directions, their effect will be equal to their difference, and the direction will be that of the greater force.

35. When two or more forces act upon the same point in different directions, their effect may be concentrated into one force, for the body only moves in one direction, and this one force is called their *resultant*. (*Composition of Forces.*)

36. When two forces acting in the same plane meet at a point, their resultant is intermediate in direction, and in the same plane.

37. If two forces which act upon a point be represented in magnitude and direction by lines drawn from

that point, then if these lines be caused to form the two sides of a parallelogram, and it be completed, the resultant of the forces will be represented by the diagonal of the parallelogram which passes through the point (*Parallelogram of Forces*). Thus if a particle at A be acted upon simultaneously by two forces represented in magnitude and direction by the lines A B, A C (N. 32), the resultant may be found by completing the parallelogram A C D B, and drawing the diagonal A D.

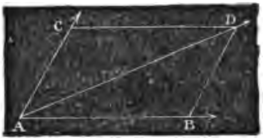

Fig. 1.

38. As several forces acting upon a point may be composed into one resultant (N. 35), so may one force acting upon a point be resolved into several components. (*Resolution of forces.*)

39. A *machine* (μηχανὴ, a contrivance) is an appliance by which a force may be transmitted either unaltered, or altered as to magnitude and direction. Thus the force of a horizontal current of water may be converted into the circular motion of a water-wheel, and this again may be applied to raise weights, turn mill-stones, or perform other work.

40. In any machine we may distinguish two principal forces—viz. the *power* applied to the machine, and the *resistance* (often expressed as weight) which the power has, through the intervention of the machine, to overcome.

41. All machines, however complicated they may be, are composed of one or more of the so-called *Mechanical Powers*:—*The Lever; The Inclined Plane;* and *The Cord.*

42. These Powers may be further divided as follows:—1. The Lever, into (α) *Levers proper*, (β) *The Wheel and Axle.* 2. The Inclined plane, into (α) *The Inclined Plane*, (β) *The Wedge*, (γ) *The Screw.* The Cord, into *The Pulley.*

43. A *lever* (*levo*, to raise) is a rigid bar capable of motion about a fixed support or axis called the *fulcrum* (*fulcrum*, a prop).

44. By a *rigid* body is understood any mass of matter in which the particles tend to preserve the same relative positions, and which hence offers resistance to change of form.

45. The forces acting on such a system are the *power* and the *resistance*, the positions of which relatively to the fulcrum vary in different kinds of lever, and serve to determine the nature of the lever.

46. Levers are of three kinds: in the first the fulcrum is placed between the power and the resistance. An ordinary balance, a steelyard, a crowbar, and a pump-handle, are examples.

47. In levers of the second kind the resistance is applied between the power and the fulcrum. A gate moving on its hinges, and the oars of a boat, are examples. In the latter instance the hand of the oarsman is the power, the boat is the weight moved, and the water is the fulcrum.

48. In levers of the third kind the power is applied

between the resistance and the fulcrum. Common tongs, forceps, and the treadle of a turning-lathe, are examples. In the latter instance the foot is the power, the crank of the lathe is the resistance, and

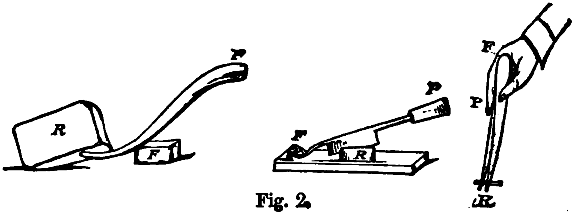

Fig. 2.

the hinge is the fulcrum. In the above figure we have examples of the three kinds of lever. In each instance P represents the power, R the resistance, and F the fulcrum.

49. In the human body there are various examples of each of the three kinds of lever:—thus the skull moves upon the atlas as a fulcrum, and the pelvis upon the heads of the thigh-bones; in each instance the fulcrum is between the power and the resistance, and the lever is therefore of the first kind. When the body is raised upon the toes, the ground acts as a fulcrum, the weight of the body is the resistance, and the muscles of the leg applied to the heel, the power; hence this is an example of a lever of the second kind. When, a weight being held in the hand, the forearm is bent upon the upper arm, we have an example of a lever of the third kind; for the weight is the resistance, the elbow-joint is the fulcrum, and the biceps muscle which is attached to the radius of the forearm near the elbow-joint is the power. In the figure, F represents the fulcrum—viz. the axis of the elbow-joint, P the power applied at the point

of attachment of the biceps muscle, and R the resistance—viz. the weight held in the hand. Now if the distance between F and P be two inches, and the distance between F and R be 12 inches, the biceps will have to exert a force of 6 lbs. to raise 1 lb. in the hand (*v.* N. 52). But the hand describes a much larger arc than P in the same time (*v.* N. 53).

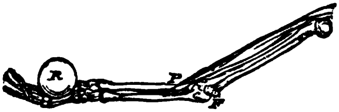

Fig. 3.

50. The two *arms* of a lever are respectively (α) the portion included between the power and the fulcrum; and (β) the portion included between the resistance and the fulcrum.

51. The *moment of the power* is found by multiplying the weight which represents the power by its perpendicular distance from the fulcrum; and the *moment of the resistance* by multiplying the weight which represents the resistance by its perpendicular distance from the fulcrum.

52. In any form of lever it is obvious that each arm moves about the fulcrum as a common centre, in arcs which are of greater or lesser amplitude, as the end of the arm is more or less distant from the fulcrum. The condition of *equilibrium* of any lever is that the power and weight are inversely as their respective distances from the fulcrum. Thus if P = the power, and W the weight, d the distance of the power from the fulcrum, and d′ the distance of the weight from the fulcrum;

$$P : W :: d' : d$$
$$\text{or } P \times d = W \times d'$$

Then P . d = the moment of the power, and W . d′ = the moment of the weight. Thus taking the inch and the pound as our units, let us imagine a straight lever without weight, on the right arm of which we have 10 lbs. at a distance of 10 inches from the fulcrum; the moment tending to depress the right arm will be 100, and the lever may attain a condition of equilibrium either by 100 lbs. placed on the left arm at a distance of 1 inch from the fulcrum, or by 4 lbs. placed at a distance of 25 inches, or by 1 pound placed at a distance of 100 inches. Or we may take the example shown in the figure.

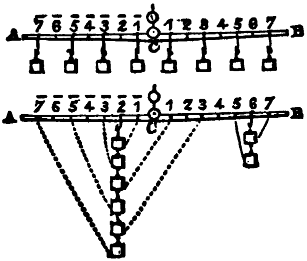

Fig. 4.

53. A machine cannot generate force, it merely serves to transmit it. In levers, for instance, power is only gained at the expense of time, or variation of velocity: thus if a weight of 1 lb., which is 101 inches distant from the fulcrum of a lever, raises a weight of 10 lbs. on the opposite arm distant 10 inches from the fulcrum, the rate at which the 1 lb. moves, and the space it moves through, is so much greater than the rate at which the weight of 10 lbs. moves and the

space it moves through, as the latter weight is greater than the former.

54. The *wheel and axle* is one of the simplest applications of the lever. It consists of a wheel fastened to an axle, which latter can move freely in bearings which serve as fulcra. The resistance (usually a weight attached to a cord) is applied to the circumference of the axle, and the power to the circumference of the wheel. The system is in equilibrium when the power is to the weight as the radius of the axle to the radius of the wheel. Thus if $P =$ the power, $W =$ the weight, r the radius of the wheel, and r' the radius of the axle—

$$P : W :: r' : r$$
$$\textit{or}\ P \times r = W \times r'.$$

In fact we have two forces at the end of two arms of a lever, the moment of the power being found by multiplying the weight representing the power by the distance between the circumference of the wheel and the centre of the axle, and the moment of the resistance by multiplying the weight representing the resistance by the distance between the circumference of the axle and the centre of the axle.

55. The *inclined Plane* is a plane inclined to the horizon at any angle, called the angle of inclination. If a body be placed upon such a surface it will tend to slide down it, and equilibrium can only exist when three forces act upon the body—viz. (α) its weight, (β) the resistance of the plane, (γ) the friction existing between the surfaces, or if this be insufficient an external force besides. If the weight consists of as many pounds as there are inches in the length of the plane, the pressure on the plane will be equal

to as many pounds as there are inches in the base, and the tendency to descend the plane will be balanced by as many pounds as there are inches in the height of the plane. The power (P) is to the resistance (R) as the height of the plane (h), is to its length l:—thus,

$$P : R :: h : l$$
$$\textit{or}\ P \,.\, l = R \,.\, h.$$

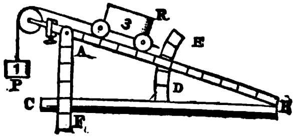

Fig. 5.

The circumstances under which equilibrium is attained by a body placed upon an inclined plane may easily be determined by the simple apparatus shown in the woodcut. The angle of inclination of the board A B is measured by the divided arc E D, and the height of the plane by the rod A F; then the relationship of the power P to the resistance R may be ascertained when equilibrium has been established.

56. By *equilibrium* (*æquus*, equal, *libra*, a balance) is understood that condition in which several forces, acting on a mass of matter, are so related that no motion of the mass results :—in other words, the forces balance each other.

57. The movable inclined plane or *wedge* usually has the form of a triangular prism with plane sides. It is often used for separating bodies which cohere with great force; all cutting instruments, together with pins, needles, and nails, are wedges.

58. The *Screw* is an inclined plane wound round a cylinder. The coils are called the *threads* of the screw, and they usually move in the interior of a cylinder which has a continuous spiral cavity corresponding to the thread. Power may be readily transmitted by screws; it is obvious that a single revolution of a screw will move any resistance placed at its extremity through a space equal to that which separates two contiguous threads, and it is equally obvious, that by using a long lever to move the screw, a great amount of force may be concentrated into a very little space.

59. Force may be transmitted by a flexible cord, and the direction of transmission may be varied by causing the cord to pass over a grooved wheel, by which latter means also friction is lessened. Such an arrangement is termed a *Pulley.* The mechanical advantage of the pulley depends on the fact that the tension of the cord or system of cords is the same in every part of their length, and is equal to the power.

60. When two bodies slide over each other, or when they move in any liquid or gaseous medium, a certain resistance to the motion is experienced. This resistance is called *friction.*

61. We already know (N. 52) that a lever will be in equilibrium when the moments of the forces on each side of the fulcrum are equal to each other. The fulcrum is the point about which the system is balanced, and all bodies, whatever may be their shape, are capable of being balanced about a certain point, at which point the whole weight of the body is virtually concentrated. This point is called the *Centre of Gravity* of the body.

62. The force of *Gravity* is an attractive force exerted between masses of matter exercised through a sensible space. The force of the earth's gravity is measured by what we call the *weight* of a body (N. 27).

63. The force of gravity exerted upon a body is in the direction of a line joining the centre of gravity of that body, and the centre of the earth. Thus, if E represent the earth, the plumb-lines A, B, C, and D, at opposite extremities of diameters, will each be directed towards the centre of the earth, and their centres of gravity will be in a line with it.

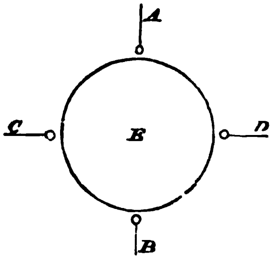

Fig. 6.

Experimental Illustration of Statics.

This branch of science does not admit of such complete illustration as many of the other sciences. Diagrams should be freely used in the description of the various mechanical powers, the composition and resolution of forces, and for problems connected with the centre of gravity. The general properties of matter scarcely admit of illustration: *porosity* may be shown by the absorption of a gas (say ammonia) by charcoal, and by the experiment of causing the atmospheric pressure to force mercury through a cylinder of oak three or four inches long. To illustrate *cohesion*, we may take the two freshly-cut plane surfaces of a leaden bullet, press them together, and determine the force necessary to separate them. The intensity of the attraction of cohesion may be also illustrated by that capital experiment in which the contraction of a thick iron bar is caused to break a small bar of cast-iron, whose middle portion resists (as long as it can), the contracting force of the larger bar. Specimens of gold-leaf, and of the fine platinum wire used for certain experiments in voltaic electricity, afford good examples of *malleability* and *ductility*. *Elasticity* may be shown by attaching weights to a brass wire suspended vertically; then it will be seen that a certain weight stretches the wire to such an extent that on the removal of the weight it recovers its original length; while a certain greater weight stretches it beyond the limits of perfect elasticity, and now it remains stretched after the removal of the weight; and a still greater weight ruptures the wire. The *composition of forces* may be illustrated by imparting two distinct simultaneous impulses, at right angles to each other, to an ivory ball on a smooth table, or by a special apparatus for the purpose. The *mechanical powers* may be made by a carpenter, with proper directions. The levers should be graduated to illustrate *moments*. Very fair metal pulley-wheels may be procured from ironmongers, but if they are required for any special purpose, they must be very carefully made, and should then be procured from instrument-makers. Cylinders of lead, with small brass hooks, are easily cast; they should represent weights from half-an-ounce to two pounds, or from a gramme to a kilogramme. Blocks of wood may be readily cut into oblique cylinders, prisms, trapeziums, etc., for illustrating the centre of gravity.

DYNAMICS.

64. DYNAMICS is that branch of Mechanical Philosophy which treats of forces which are not in equilibrium, and which therefore produce motion in bodies (comp. Notes 25, 28).

65. A body is said to be moved when it occupies different positions in space during successive instants of time. Thus, to study the motion of bodies, we must take into account (α) the nature of the space described; (β) the time; (γ) the rate at which the body moves; and (δ) the direction of the motion (N. 30).

66. Space may be either of one dimension (*length*); of two dimensions (*surface*); or of three dimensions (*volume*). The English *unit of length* is the *yard*, which is determined by means of a pendulum vibrating seconds in the latitude of London, and is equal to 36 inches, or 91·438348 centimètres. The French unit of length is the *mètre*, which is nearly the ten-millionth part of the quadrant of a meridian passing through Paris, and is equal to 39·37079 inches, or 1·09363305 yard. The *units of surface* may be respectively the *square yard*, equal to 0·836097 square metre; or the *square metre*, equal to 1·196033 square yard. The *units of volume* may be respectively the *cubic yard*, or the *cubic metre*. But it must be borne in mind that different units are used for different purposes; thus, the *foot* and the *inch*, the *decimetre* and the *centimetre*, with the surfaces and volumes deducible from them, are often used as units.

67. The *unit of time*, or *duration*, is usually the *second*, which is the 86,400th part of a mean solar day.

68. The *unit of velocity* varies with different writers. In the case of falling bodies, projectiles, and sound, it is usually taken as a velocity of one foot, or one metre, per second; while in the case of light and electricity it is expressed in miles or kilometres per second.

69. The line of motion of a body may be either straight or curved. When a stone is allowed to fall to the earth it moves in a straight line, while a bullet projected from a gun, or a stone thrown into the air, describe curved lines.

70. When a body moves in a curved line, the direction of its motion is perpetually changing; and the direction at any point of its line of motion is tangential to the line at that point; that is, the motion is in the straight line in which the body would move at any instant if suddenly released from the action of the force which causes it to follow its curvilinear path.

71. Velocity, or *rate of motion*, may be either *uniform* or *variable:* it is uniform when the velocity is the same at each instant of time, that is, when the moving body passes over equal spaces in equal intervals of time. Thus, if a body passes with uniform velocity through space s in the time t; that is (if feet and seconds be our units) through s feet in t seconds, it will pass over $\frac{s}{t}$ feet in one second. Now since the velocity (v) of a body, taking the above units, will be the number of feet it describes in one second, it is obvious that

$$v = \frac{s}{t} : \text{ hence } s = vt.$$

Thus if any two of the three quantities s, v, t, be given, we can find the third.

72. Velocity is *variable* when the moving body does not pass through equal spaces in equal times, that is when the velocity is not the same at each instant of time. The velocity, at any instant, of a body moving with a variable velocity, is measured by determining the space through which it would pass in a unit of time, if the velocity which it possesses at that instant were maintained during the unit of time.

73. The *mean velocity* of a body moving with a variable velocity is found by dividing the space through which it passes in a given time, by the time. Thus, if a body moves through 1000 feet in a minute, and if its velocity at a point a be 20 feet a second, and at another point b be 10 feet a second; we should say that the mean velocity of the body is $\frac{1000}{60}$, that is 16·6 feet per second, while the actual velocities at the points a and b are respectively 20 and 10 feet per second.

74. Velocity is said to be *uniformly accelerated* when it is increased by equal quantities during equal intervals of time. In this case if a be the acceleration for a second of time, the velocity at the end of the first second will be $V + a$; at the end of the second second $V + 2a$; and at the end of n seconds $V + na$; if V be the initial velocity.

75. Velocity is said to be *uniformly retarded* when it is diminished by equal quantities during equal intervals of time.

76. The quantity of motion associated with a body is termed its *momentum* (*moveo*, to move), and is expressed by the number of units of mass (N. 26) which the body contains, multiplied by the number of units of velocity (N. 68) which gives it motion. Thus, if feet and pounds be taken as the units, the momentum of a mass weighing 10 lbs. moving with a velocity of ten feet a second, will be 100; and of a mass weighing 1 cwt. moving with a velocity of 0·25 foot, the momentum will be 28. If m represents the mass of a body, and V its velocity, then $m\ V$ will represent its momentum.

77. Again, if F represent a force which produces a velocity v *in a unit of time* in a mass, m then $F = m\ v$. In other words, the momentun produced in a unit of time is proportional to the force producing it. This force is sometimes called the *effective force* of the body.

78. The *unit of force* is the force which will impart a unit of velocity (N. 68) to a unit of mass (N. 26) in a unit of time (N. 67). Thus, if our units are respectively a foot, a pound, and a second, the unit of force would be that force which, if caused to act for one second upon a weight of one pound, will generate in it a velocity of one foot per second.

79. In this country the *Unit of Mechanical Work*, called a *Footpound*, is the mechanical force necessary to lift 1 lb. to a height of 1 foot in a vacuum. On the Continent the unit of work, called a *Kilogrammetre*, is the mechanical force necessary to lift one kilogramme (2·2046215 lbs. Avoirdupois) to a height of 1 metre (3·2808992 feet) in a vacuum.

80. The *First Law of Motion* asserts that a body will continue in a state of rest, or of uniform rectilinear motion, unless it be acted upon by an external force. This is obviously a definition of that property of matter which we have before described as *inertia* (N. 12); hence this is sometimes called the *law of inertia.*

81. *Second Law of Motion.*—Change of motion produced in a body is proportional to the force which produces it, and takes place in the direction of that force. Or the law may be otherwise expressed thus: —If a force acts upon a body in motion, the change of motion which it produces is the same in magnitude and direction as if the force had acted upon the body at rest. And if any number of forces act at once, each one tends to generate a velocity in its own direction.

82. This may be readily exemplified by the law of the *composition of velocities.* We have already seen (N. 35, 37) that the resultant of two forces acting simultaneously upon a body may be represented by the diagonal of a parallelogram, whose sides represent both in magnitude and direction the forces. In like manner, let us suppose a body *A* (Fig. 7) animated by a motion represented by the spring F, which motion, if acting alone, will in one second bring it to a point *B*, and also by a second motion represented by the spring E, which motion, if acting alone, will cause it in one

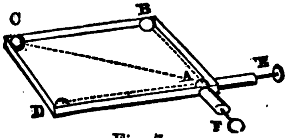

Fig. 7.

second to move to a point D in a direction at right angles to its former motion; then, if we complete the parallelogram, and simultaneously release the springs E, F, the body will move along its diagonal, and in one second will be found at the termination of the diagonal—viz. at C.

83. *Third Law of Motion.*—Action and reaction are equal and contrary.

84. *Action* here includes the momentum (N. 76) which one body receives when another acts upon it; while *reaction* includes the momentum which one body loses by communication to another body.

85. If a body which is suspended above the earth's surface be released, it falls under the action of the force of Gravity (N. 62), with a uniformly accelerated velocity (N. 74).

86. Gravity acts equally on each of the particles composing a mass, and all bodies, whether heavy or light, fall to the earth with the same velocity if the resistance of the air be avoided.

87. Newton's law of Universal Gravitation asserts that every substance in the Universe attracts every other substance with a force which is proportional to the mass of the attracting bodies, and which varies inversely as the square of the distance between the attracting bodies. Thus, let us suppose two masses at a certain distance from each other, and exercising a certain attraction, in each instance taken as unity. If the mass of one be increased tenfold while the other remains the same, the attraction becomes 10. If the mass of one be increased five-fold, and of the

other ten-fold, the whole attraction will become 50; for each unit of the one body will attract each unit of the other with unit force, and the sum of these attractions will obviously be 10 × 5. Again, if in this last instance the distance between the masses be increased five-fold, the attraction becomes 2: for $\frac{10 \times 5}{5 \times 5} = \frac{50}{25} = 2$.

88. The velocity of a body descending under the influence of gravity increases in direct proportion to the time; for the force of gravity is acting upon the body at each and every instant of its fall, so that the ultimate velocity is the sum of all the small and equal velocities imparted during its descent. Thus the velocity at the end of two seconds is double the velocity at the end of one second, at the end of three seconds treble, and at the end of n seconds n times. In fact, the velocity is uniformly accelerated (N. 74). Hence, if g be the acceleration given to a body falling under the influence of gravity for one second = 32·2 feet in London; and V = velocity, and t time:

$$V = gt$$

For instance, the velocity at the end of the third second will be $V = 32{\cdot}2 \times 3 = 96{\cdot}6$ feet.

89. A body falling under the influence of gravity acquires a velocity of 32·2 feet per second at the end of the first second. That is, if gravity were suddenly annihilated it would continue to move with an uniform velocity of 32·2 feet per second. Since during this first second of fall the body at starting had no velocity, and acquires a velocity of 32·2 feet, the *mean velocity* (N. 73) will obviously be 16·1 feet; that is, the body falls during the first second through 16·1 feet. During the second second the body falls through 32·2

feet, in virtue of its initial velocity *plus* 16·1 feet due to the action of gravity during that second, acquiring a final velocity of 64·4 feet per second. Again, during the third second the body is carried through 64·4 feet, in virtue of its initial velocity, *plus* 16·1 feet due to the direct action of gravity, acquiring a final velocity of 96·6 feet per second. If S = the space passed through by a falling body; and g, V, t, as before (N. 88):

$$S = \tfrac{1}{2}gt^2 = \tfrac{1}{2}\ Vt.$$

that is, S is equal to the average velocity multiplied by the time. Thus the space passed through during three seconds will be

$$S = \frac{32{\cdot}2 \times 9}{2} = \frac{289{\cdot}8}{2} \text{ ft.} = 144{\cdot}9 \text{ feet.}$$

90. Hence when a body falls from rest under the influence of gravity, the velocity acquired varies as the time of descent, and the space through which the body falls varies as the square of the time.

91. The above laws apply equally to every uniformly accelerated motion.

92. The accelerating force of gravity (g) varies at different points of the earth's surface. Thus at Trinidad g is equal to 32·0913 feet per second, while at Spitzbergen it is equal to 32·2528. The variation is due to two causes. Firstly, the earth is not a true sphere, but a spheroid whose diameter at the equator is 26·47 miles greater than the diameter at the poles. Hence any point near the equator is farther from the centre of mass of the earth than a point nearer the poles, and the force of gravity is less at the former than at the latter. The second cause is the revolution of the earth and the centrifugal force produced thereby.

For it is obvious that the centrifugal force at the equator is far greater than at the poles, where indeed it is practically *nil*, while a particle at the equator moves nearly 3 miles in a second. The force which produces motion in a falling body is the force of gravity minus the centrifugal force; hence the difference. Thus a body which at Paris weighs 1000 grammes, will weigh 1000·221 grammes at either pole, and 997·108 grammes at the equator.

93. If a body be projected upwards, gravity acts as a uniformly retarding (N. 75) force, and deprives the ascending body of equal amounts of its velocity in equal times. Thus if a body be projected upwards with a velocity of 32·2 feet, the force of gravity, which tends to pull it down with a velocity of 32·2 feet per second, will arrest it at the end of one second; and during that second it will obviously have moved with an average velocity of $\frac{32{\cdot}2 + 0}{2} = 16{\cdot}1$, and will hence have risen to a height of 16·1 feet. Or if a body be projected upwards with a velocity of 64·4 feet, it will ascend for two seconds before gravity can reverse its motion, and will reach a height of 64·4 feet with an average velocity of $\frac{64{\cdot}4 + 0}{2} = 32{\cdot}2$ feet. In fact, if we double the velocity with which a body is projected upwards, it ascends to four times the height; if we treble the velocity, it ascends to nine times the height, and so on.

94. If a body be projected vertically upwards with any velocity, it will have acquired, on reaching the ground again, under the influence of the force of gravity, a velocity equal and opposite to that which it possessed at starting.

95. We may determine the height to which a body will rise if projected vertically upwards with a known velocity, by estimating the height from which it would require to fall under the force of gravity in order to acquire its initial velocity. The time which a body projected upwards will take to rise to its highest point, may be found by determining the time which it would take to fall from that point under the influence of gravity.

96. If a body be projected horizontally through space, or in any direction other than vertically upwards or downwards, it follows a curved path, under the joint action of the projectile force in one direction, and the force of gravity in another. Let us suppose that the body is projected horizontally in space, and that its velocity would cause it to pass over 20 feet in one second; in the same interval of time gravity will cause it to descend through 16·1 feet, and the actual position of the body at the end of the second will be the extremity of the diagonal of a parallelogram (N. 37) whose sides are respectively (α) the space which the body would pass through under the influence of the projectile force acting alone; and (β) the space which the body would pass through under the

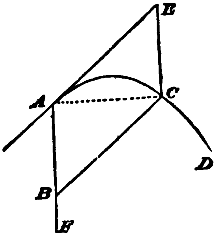

Fig. 8.

influence of gravity acting alone. And so for the second and succeeding seconds. The summation of all these diagonals produces a continuous parabolic curve. If a body at A, Fig. 8, be projected upwards with a force which in a given time would, if acting alone, carry it to E, while the force of gravity, if acting alone, during the same time would cause it to fall to B, the path of the body will be represented by A C.

97. A *pendulum* (*pendeo*, to hang, suspend—hence a suspended body) is a small heavy mass of matter suspended by a thread from a fixed point. It is in fact a mass of matter constrained to move in a circular arc about the point of suspension as a centre.

98. If such a mass, called the *bob* of the pendulum, be drawn aside from its position of rest, and released, it will fall from its position to the vertical line, and pass it to a distance on the other side equal to that from which it fell, and will continue to oscillate through equal angles on opposite sides of its normal position of rest, which is in a line with the centre of the earth. Thus, if the pendulum A be drawn aside from its position of rest at C, it will in returning pass C and rise to a height B on the other side.

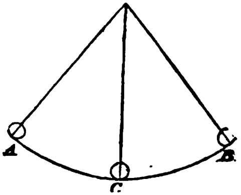

Fig. 9.

99. The motion of the bob of a pendulum, from its

greatest elevation on one side to its greatest elevation on the other, is called an *oscillation* or *vibration;* the arc which it describes is its *amplitude* of oscillation; and the time which it requires to describe this arc is the *duration* of an oscillation.

100. The following are the laws which regulate the vibration of pendulums:—

(α) The vibrations are isochronous: that is to say, the same pendulum executes a vibration, whether it be in a small or large arc, within certain limits, in the same time. Therefore, the larger the amplitude of vibration, the greater the speed.

(β) The time of vibration is not affected by the material of the pendulum. As gravity acts upon all bodies with equal effect (N. 86), it is obvious that balls of dissimilar substances—metal, stone, wood,—suspended by strings of equal length, will vibrate in the same time, if the resistance of the air be abolished.

(γ) The time of vibration varies as the square root of the length of the string. Thus the length of a pendulum which completes one vibration in a second, in London, is 39·1393 inches; and if the string be reduced to one-fourth this length, or 9·76175 inches, it will oscillate twice in a second; if reduced to one-ninth, or 4·3385 inches, it will oscillate three times in a second, and so on.

(δ) The time of vibration varies inversely as the square root of the force of gravity at the particular locality in which the experiment is made.

101. The *centre of oscillation* of a pendulum (*oscillum*, a swing) is a point in a pendulum such that, if the

whole mass of the body were there present, the oscillations would be performed in the same time. The length of a pendulum is the distance between its centre of oscillation and point of suspension.

102. The term *energy* (*ἐνέργεια*, action, operation), is used in Natural Philosophy to signify the power of doing work in opposition to gravity, or some other force. Thus, when a mass is raised from the earth, or a keeper separated from a magnet, or an attracted body from a conductor charged with electricity, energy has been expended.

103. Energy is of two kinds, *potential* and *kinetic;* it possesses, if we may so express it, an active and a passive form.

104. *Potential energy,* or energy of position, is energy existing in possibility, not in act; as in the case of a mass of matter suspended above the surface of the earth, or an arrow resting upon a tense bow-string.

105. *Kinetic energy,* or energy of motion, is the actual energy possessed by a body in motion, as in the case of a body falling to the earth, or an arrow released from a tense bow-string.

106. When the bob of a pendulum is drawn aside from its position of rest, it is in the position of a raised weight; that is to say, it has been placed in a position of advantage with regard to gravity, because it can now fall: it possesses *potential energy* (N. 104). When released, it gradually exchanges its potential energy for actual or *kinetic energy* (N. 105); and at its lowest point, or usual position of rest, it has con-

verted all its potential into kinetic energy. When it rises again on the other side of the vertical, its kinetic energy becomes potential, and so on. Thus the kinetic energy of a pendulum bob is that which it would acquire by falling freely under the influence of gravity from the summit of its oscillation to its lowest position.

107. The velocity which a body acquires in falling down an inclined plane is equal to the velocity which it would acquire by falling down the vertical height of the plane. Suppose a body resting upon an inclined plane the vertical height of which is one foot; it is obvious that the body possesses a certain amount of potential energy, or energy of position, for it is now one foot farther distant from the centre of the earth than before, and it can fall through this space, thereby converting its potential into actual energy. And if the plane be perfectly smooth, the body will acquire precisely as much kinetic energy in sliding down the plane as it would have acquired by falling through the vertical height of one foot (v. also N. 55).

108. If a body revolves about a centre, the motion of a radius joining it with that centre indicates what is called the *angular velocity* of the body. If the body moves with uniform velocity, it is obvious that equal arcs will be described in equal times; and the angular velocity is then said to be uniform, for the angles included between any successive radii are equal.

109. The kinetic energy of such a body remains constant.

110. If a body moves in an ellipse under the influence of an attractive force, the energy varies in differ-

ent parts of its path. For suppose the attracting body to be placed in the focus of an ellipse, as is sometimes the case of the sun and a comet. It is obvious that the body will move fastest when nearest the attracting body, and slowest in the more distant portions of its path. At the most distant part of its path, just before it rounds the end of the ellipse, its kinetic energy has become potential energy, and it gradually acquires an increase of *vis viva* in again falling towards the sun.

111. If two inelastic bodies moving in opposite directions come into collision, a portion of the energy of motion becomes heat, or effects electrical separation, and the united mass moves in the direction of the mass which before impact possessed the greatest momentum. Thus, let us suppose a mass A, weighing 10 lbs., moving with a velocity of 10 feet, meets a mass B, weighing 5 lbs., moving with a velocity of 12 feet; the momentum in one direction will be 100, and in the other 60. Thus the excess of momentum in the direction of A will be $= 100 - 60 = 40$, and the combined masses A and B $= 10 + 5$ lbs. will now possess a momentum $= 40$, and will move with a velocity $= \frac{40}{15} = 2 \cdot 66$.

112. If two perfectly elastic bodies impinge upon each other, none of their kinetic energy is converted into heat or electricity.

Experimental Illustration of Dynamics.

Dynamics, like Statics, must be chiefly illustrated by means of diagrams and the black-board. The apparatus to be employed is not extensive, but every-thing must be specially constructed for the purpose. A whirling table to illustrate centrifugal force, and a delicately-suspended pendulum, are essentials. So also is an Atwood's machine for illustrating the laws of falling bodies. The friction-wheels of the latter must be of the most accurate workmanship, hence Atwood's machine is a somewhat expensive piece of apparatus. A serviceable form of the machine for lecture purposes may be procured for £10, but a machine with delicate friction-wheels and great-fall costs twice or thrice as much. Mr. Ball has described some new and very ingenious forms of dynamic apparatus in his recent work on mechanics.

HYDROSTATICS.

113. *Hydrostatics* is the science which treats of liquids at rest; and of the conditions of equilibrium under which liquids, acted upon by external forces, exist. (ὕδωρ, water, στάω, ἵστημι, to stand, remain.)

114. Liquids differ from solids in the greater mobility of their particles. In solids, cohesion (N. 13) predominates, and does not permit the molecules to oscillate in arcs of great amplitude; while in liquids the amount of molecular motion is relatively greater, the molecules oscillate in larger arcs, and are therefore less restrained by cohesion, hence results the increase of molecular mobility. (Notes 224 and 226.)

115. The molecules of liquids glide with greater or lesser ease over each other, hence liquids readily accommodate themselves to the shape of the vessel in which they are placed. It is obvious, however, that liquids possess a certain amount of cohesion, from their varying viscosity; for instance, treacle, water, and alcohol, possess very diverse degrees of molecular mobility.

116. The phenomena of *Capillarity* (*capillus*, a hair) or *capillary attraction* are due to the cohesion of liquid molecules, and to the attraction which takes place between them and solid bodies. If a solid is placed in a liquid which wets it, the liquid in contact with the sides rises in opposition to the force of gravity, and forms a concave surface. On the other hand, if it does not wet the solid the liquid is depressed at

the points of contact and forms a convex surface. In fine tubes these effects are far more apparent. They depend upon the relationship which exists between the cohesion of the liquid and the attraction of the particular solid with which it may be in contact.

117. Liquids were once believed to be incompressible: Dr. Stephen Hales hammered a wooden peg into a bomb full of water, and found that the peg "was bruised to pieces between the hammer and the resisting water;" Lord Bacon enclosed water in a sphere of lead, and on compressing the sphere noticed that the water exuded through the metal (*Novum Organum*, lib. 2, aph. 45); the Members of the Accademia del Cimento tried the same experiment with a sphere of gold, and with the same result: thus proving both the porosity (N. 10) of the densest bodies, and the slight compressibility of water. By the employment of suitable means the compressibility of liquids has been measured: for a pressure of one atmosphere (15 lbs. on the square inch of surface), mercury was found to be compressed by one three-millionth part: water one fifty-millionth: and ether one hundred and eleven-millionth; of its original volume, in all cases at 32° F. (0° C.) In every instance the liquids gained their original volume on the removal of the pressure, and are hence perfectly elastic. (N. 21.)

Dr. Hales gives the following account of the experiment mentioned above:—"In order to try the incompressibleness of water, I filled the bomb, before it was burst, with pump water, well purged of air, which had 6½ degrees of coldness above the freezing point; then placing it under the cyder press, I pressed fast into its orifice a plug, which had a hole through it from top to bottom of about half-an-inch diameter, into which hole I drove, with a hammer, a strong tough ashen pin, which was covered with cement. When the pin, which was half-an-inch diameter, was so fast driven in, that no water could pass by it, it then met with so absolute a resistance from the water, that it seemed as if the lower end of the pin had been driven against a stone or solid iron, so that on striking very hard blows with the hammer, the pin was bruised to pieces between the hammer and the resisting water." Lord Bacon describes his experiment as follows:—"Fieri fecimus globum ex plumbo cavum, qui duas circiter pintas vinarias contineret; eumque satis per latera crassum, ut majorem vim sustineret. In illum aquam immisimus, per foramen alicubi factum; atque foramen illud, postquam globus aqua impletus fuisset, plumbo liquefacto obturavimus, ut globus deveniret plane consolidatus. Dein globum forti malleo ad duo latera adversa complanavimus: Ex quo necesse fuit aquam in minus contrahi, cum sphæra figurarum sit capacissima. Deinde, cum malleatio non amplius sufficeret, ægrius se recipiente aqua, molendino seu torculari usi sumus; ut tandem aqua impatiens pressuræ ulterioris, per solida plumbi (instar roris delicati) exstillaret."

118. Liquids transmit pressures equally in all directions. If pressure be applied at any point of a confined liquid mass, it is transmitted without sensible loss in all directions, and hence acts with the same force on all areas equal to that of the area of original pressure, and in a direction at right angles to such surfaces. This is known as *Pascal's Law*.

119. Thus the pressure transmitted by a liquid is directly proportional to the extent of surface. We may prove this by taking two communicating cylindrical vessels of unequal diameters, filling them with water, and fitting pistons into their open upper extremities: if one piston has a hundred times the surface of the other, a weight of 1 lb. on the latter will balance a weight of 100 lbs. on the former. If P denote the pressure, and A the cross section of the large piston;

p the pressure, and a the cross section of the small piston; then

$$P = p \times \frac{A}{a}$$

It is obvious that if great disproportion exists between A and a, a small pressure may produce a pressure of considerable magnitude. This is the principle of the *Hydrostatic Press* (sometimes called the Hydraulic Press, or Bramah's Press).

120. It is to be noted, however, that in the above instance, if the small piston be employed to give motion to the large one, power is gained at the expense of velocity (N. 53). For in consequence of the difference of section of the two pistons, if the small piston moves through a certain space, the large piston will only move through one-hundredth of that space.

121. Under the influence of gravity (N. 62) the free surface of liquids is a horizontal plane, at right angles to the direction of the force of gravity (N. 63).

122. If we imagine any liquid mass to be divided into a succession of horizontal layers, the pressure in each layer is proportional to the depth of liquid above it.

123. In any such horizontal layer it is obvious (from Notes 118 and 121) that the pressure is the same at all points.

124. Columns of different liquids of the same height exert pressures which are proportional to the densities of the liquids. Thus, if we double the density of a liquid (the depth remaining constant), the pressure on an equal area will be doubled. (N. 27.)

125. If two liquids of different densities are placed in vertical cylinders, open above and communicating by their lower part, equilibrium will be established between them, when the heights above the point of contact of the two liquid columns are inversely proportional to their densities. Thus, if a column of water 100 inches high is balanced by a column of mercury 7·35 inches high, if the density of water be taken as unity, and we call the required density (of the mercury) x; we have—

$$7{\cdot}35 \times x = 100 \times 1.$$

$$\therefore\ x = \frac{100}{7{\cdot}35} = 13{\cdot}59.$$

126. The pressure exerted by a liquid is altogether independent of the form of the vessel which contains it, and of the quantity of liquid, but depends upon the density of the liquid and its depth.

127. As liquids transmit pressure equally in all directions (N. 118), the pressure of the upper layers is exerted both horizontally and vertically upwards. This upward pressure may be readily shown by the following means:—A glass tube, g (Fig. 10), is provided with a tightly-fitting movable bottom, B, which can be kept in its place by the string v. If now the whole be lowered into a vessel of water $n\ n$, the movable bottom B will be supported by the upward pressure of the water, and water may be poured into g, until it nearly reaches the level $n\ n$, when B falls down.

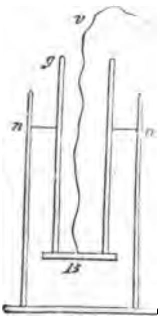

Fig. 10.

128. This upward pressure is called the *buoyancy* of the liquid.

129. When a body is immersed in a liquid the upward pressure exerted upon it is equal to the weight of the volume of liquid which it displaces; or, otherwise, when a body is immersed in a liquid it loses a portion of its weight equal to the weight of the liquid which it displaces. That this must be the case is sufficiently obvious: for let us suppose a fluid mass at rest, and within it, imagine any surface, enclosing any volume. Now this volume of liquid is in stable equilibrium within the mass; it is hence submitted to the action of equal and contrary pressures; the buoyancy of the liquid, and the downward attraction of gravity, are in equilibrium, and the liquid remains at rest. If the volume of liquid be replaced by a solid, the latter will receive the same support, and be submitted to the same pressures as the liquid which it displaced, and will consequently lose a portion of its weight equal to that of the liquid which it displaces.

This is the *Law of Archimedes.*

130. If we immerse in a liquid, say water, a solid heavier than water, its weight in water will obviously be equal to its weight in air *minus* the weight of a volume of water equal to its own volume. If we now immerse a body which is lighter than water, it will, on being released, rise to the surface, because the water which it displaces weighs more than its own weight in air.

131. The *Specific Gravity* of a body is its relative volume weight referred to some standard; (usually water at 4° C. 39·2° F. in the case of solids and liquids).

Thus, if we say the specific gravity of gold is 19·34, we mean that gold is bulk for bulk 19·34 times heavier than water; and that number expresses the ratio between the weight of any given volume of gold, and the weight of an equal volume of water at the same temperature and pressure. Thus gold contains 19·34 times as much matter as water, bulk for bulk. The specific gravity of a body which is heavier than water, and insoluble, is readily found by the following means:—Let the weight in air at the standard temperature be denoted by W, and the weight in water by w, then

$$\text{Specific Gravity} = \frac{W}{W - w}$$

That is to say, the weight in air is divided by the loss of weight in water, which latter is obviously the weight of a volume of water equal to the volume of the immersed body, and the quotient gives us the weight of the latter in terms of the weight of an equal bulk of water.

Experimental Illustrations of Hydrostatics.

Hydrostatics admits of considerable experimental illustration. Several vessels of different shapes, but with movable bottoms of the same area, should be used for illustrating the pressure of liquids. The hydrostatic press is an effective, but expensive, piece of apparatus. The instrument for showing the compressibility of liquids is useless for lecture purposes unless it can be illuminated by the electric light. It is also very expensive, and does not furnish a very striking proof. The law of Archimedes should be most rigidly and completely demonstrated: a body heavier than water should be weighed in air, then in water, by some serviceable lecture-balance which possesses a two-foot beam, and is fairly delicate. Then a body of the same density as water should be weighed in air, and be shown to lose all its weight in water. Finally, a hollow cylinder should be suspended to one beam of a balance, and beneath it a solid cylinder which fits it exactly. They should be counterpoised, and the solid cylinder immersed in water. Then, by filling the hollow cylinder with water, equilibrium will be restored, and the law of Archimedes will be conclusively proved. The specific gravity of bodies should be taken, and the various methods precisely explained.

HYDRAULICS OR HYDRODYNAMICS.

132. *Hydrodynamics* (ὕδωρ, water; δύναμις, force) is the science which treats of the motion of liquids; it investigates the laws which govern the actions of external forces tending to produce motion in liquid masses. The term *Hydraulics* (αὐλός, a pipe) is often applied to the science, but it is most correctly termed *Hydrokinetics* (κίνησις, motion): comp. N. 25.

133. If an orifice be made in the bottom of a vessel which is kept constantly filled with liquid, it may be proved that the velocity of efflux from the orifice is the velocity which would be acquired by a body falling freely from the height of the liquid surface to the orifice. Thus we already know that a body falls under the influence of gravity through 16·1 during the first second, acquiring a velocity of 32·2 feet per second (N. 89). Hence if an orifice be made in a vessel of water 16·1 feet below the surface, the liquid will flow from the orifice with a velocity of 32·2 feet per second. If v denote the velocity, h the height of the liquid surface above the orifice, and g the accelerating force of gravity, then

$$v = \sqrt{2\,gh}.$$

This is known as the *Law of Torricelli.*

134. The velocity of efflux is independent of the density of the liquid, as we should infer from Note 86.

If we take two vessels with orifices of the same diameter, and fill one with water, and the other, to the same height above the orifice, with mercury, the respective liquids are found to issue with the same velocity; for although the mercury is 13·56 times heavier than the water, and the pressure which it exerts on the liquid at the orifice is consequently 13·56 times greater than the pressure of the column of water, we must remember that the mercury has 13·56 times as much matter to move.

135. The quantity of liquid discharged from a vessel varies as the square root of the depth of the liquid, and it obviously depends also on the area of the orifice. It may be proved that, if we double the area of the orifice, nearly double the amount of liquid issues from it, the levels remaining constant in both cases. If several orifices are made in a vessel at depths of 1, 4, 9, 16, 25, inches (say) from the surface, the liquids will escape from them with velocities respectively related to each other as 1, 2, 3, 4, 5. If 1 pint flows from an orifice 1 inch from the surface, 3 pints will flow from an orifice 9 inches below the surface, and $\sqrt{n}$ pints from an orifice n inches from the surface.

136. From Pascal's law (N. 118) it follows that if an orifice be made in the side of a vessel containing a liquid, the liquid will flow out with the same velocity as if the orifice were at the bottom of a vessel of the same depth.

137. It is well known that if a body which, in falling through a given space, has acquired a certain known velocity, be projected upwards with the same

velocity, it will rise to the same height as that from which it originally fell (N. 93). Thus, if a body is projected upwards with a velocity of 32·2 feet per second, it will rise to a height of 16·1 feet. Hence we should expect that if a liquid be allowed to escape from a discharge pipe opening vertically upwards, the jet would rise to the height of the liquid surface in the vessel. In practice, however, this is not the case, because the liquid of the jet, when it has attained its greatest elevation, presses vertically downwards on the ascending particles beneath it; but if the discharge pipe be slightly inclined, this difficulty disappears, and the jet rises to $\frac{8}{10}$ths the height of the liquid surface. The true height is not attained on account of the liquid friction, and the resistance of the air.

138. If the efflux of a liquid from a vessel be accurately determined, it is found that the amount is only about 62 per cent of the amount required by Torricelli's law (N. 133). The cause of this was discovered by Newton, who found that the cross section of an issuing jet diminishes, until the jet attains a distance equal to half the diameter of the orifice, at which point the jet possesses its maximum amount of contraction. The area of the jet is now about $\frac{62}{100}$ths the area of the orifice. Hence Torricelli's law is accurate, if in calculating the amount of efflux we substitute the area of the contracted jet (called by Newton the *Vena Contracta*) for that of the orifice.

139. The *Vena Contracta* is caused by the rush of liquid particles towards the orifice from which the jet escapes, and towards the axis of the jet. By this means a number of converging currents are produced,

and the convergence continues beyond the orifice, attaining its maximum at the *Vena Contracta.*

140. If a jet be allowed to flow through a short cylindrical tube in place of a simple circular orifice, the amount of efflux is considerably increased. This is due to the adhesion which takes place between the liquid and the surface of the tube, which causes the *Vena Contracta* to disappear, and thus gives the jet a uniform cross section. By the use of short delivery tubes of different forms the amount of efflux may be increased to various extents.

141. If, however, the delivery tube be increased beyond a certain limit, the friction which arises between the effluent liquid and the sides of the tube is so great that it retards the efflux. Thus, for instance, if the length of a tube be 48 times its diameter, the discharge from it is reduced to about 63 per cent of that required by the law of Torricelli, and if its length be further increased the efflux continues to diminish. The motion thus lost is converted into heat.

142. If a descending jet be examined below the *Vena Contracta,* it will be seen to preserve for some distance the form of a solid cylindrical rod. Then it commences to be troubled, and to lose its transparency, and a series of alternate expansions and contractions may be noticed. If these are viewed by a revolving mirror, or by the flash produced by the discharge of a Leyden jar, they are seen to consist of a series of distinct drops, each of which forms alternately an ellipsoid with its major axis in a horizontal plane; then intermediate conditions, including a perfect spheroid;

then an ellipsoid with its major axis in a vertical plane; and so on.*

143. A jet of liquid, or gas, moving in any direction either within a tube or otherwise, is found to attract proximate bodies. In fact, the pressure exerted by a fluid in motion is less than its pressure when at rest; and the pressure of the surrounding air tends to drive contiguous bodies towards the axis of the jet. This is the *lateral action* of Venturi.

144. When a jet issues horizontally from a vessel, it behaves like an ordinary projectile, and hence follows a parabolic path: for it is acted upon by two forces—viz. the pressure which confers horizontal projection upon it acting in one direction, and the force of gravity acting upon it in a direction at right angles to this; the particles composing the jet are hence urged into a curved path: (comp. N. 96).

145. Water is frequently used as a motive power. The motion is usually communicated to some form of water-wheel, or turbine. When a fall of water is added to the ordinary horizontal motion of a stream, the effect is, of course, considerably increased. In such cases the effective force of the waterfall may be represented by $w \times h$, where w denotes the weight of water descending in a given time, and h the height through which it descends. No less than 80 per cent of the force produced by falling water may be secured by the use of suitable water-wheels. The kinetic energy (N. 105) of moving water is originally

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* At the end of this section will be found an account of some experiments on this subject made by the Author in 1867, and published in the *Philosophical Magazine* for that year.

derived from the sun (N. 271); for the water is raised to a higher level by evaporation, and it subsequently condenses. When existing in a cloud it is in a condition of potential energy (N. 104); when it falls as rain, under the action of the force of gravity, it exchanges its potential energy for kinetic energy, and is then able to perform work. In the case of water-wheels which are turned by the stream of a tidal river, the energy is derived from the attraction of the sun and moon.

146. The *Screw of Archimedes* consists of a cylinder inclined to the vertical, and capable of rotation about its axis. Around the cylinder a tube is wound in a helical form; both ends of this tube are open; and the lower end dips into water. Then, on causing the cylinder to revolve, water rises through the tube and escapes from its upper extremity. The cylinder must be inclined in such a manner that the angle which its axis makes with the vertical is greater than the angle at which the thread of the screw is inclined to the right section (at right angles to the axis) of the cylinder.

On the Constitution of a descending Liquid Jet.

It is well known that a descending liquid jet presents a perfectly smooth continuous appearance above the *vena contracta;* whereas below it a series of swellings and contractions appear, and the previously transparent jet becomes opaque.

By looking at a descending jet placed in front of a rapidly rotating strap furnished with alternate light and dark bands, Savart * found that its opaque portion was composed of detached masses of liquid; moreover he observed that the swellings of the jet were produced by drops extended horizontally, and the contractions by drops extended vertically—each drop passing through a series of oscillations, being alternately extended vertically and horizontally, and (of necessity) midway between the two positions assuming the form of a perfect sphere. He further detected very small spherical drops between the larger drops. Plateau, in a series of admirable and elegant researches ("*Sur les figures d'équilibre d'une masse liquide sans pesanteur*"), examined with great accuracy the transformation of a liquid cylinder into isolated spheres, and clearly explained the cause of the phenomena observed by Savart. One of the modes of examination adopted by Plateau was to lessen the velocity of a descending liquid jet, so that its resolution into spheres could be watched with greater ease and without the employment of Savart's strap or a revolving mirror. He effected this by causing a stream of oil to flow from a small funnel, through a column of liquid of slightly less density than the oil; it was then observed that when nearly all the oil had flowed from the funnel (that is to say, when the velocity of the effluent stream was least), the stream did not preserve its cylindrical form, but was resolved into spheres. Immediately before the separation of a sphere, a fine thread of liquid was seen to be extended between the sphere and the liquid from which it separated; and on the separation of the sphere this thread suddenly contracted into one or two minute spheres. The cause of the small intermediate drops observed by Savart was thus explained. Their formation was afterwards observed by Magnus* in the case of a descending stream of water, his observations being made with a revolving mirror, and also by means of a rapidly rotating disk furnished with a narrow slit through which the stream was viewed.

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* "Mémoire sur la constitution des veines liquides, lancées par des orifices circulaires en mince paroi."—*Annales de Chime et de Physique,* vol. liii. (1833).

The particles of liquid of a descending stream must obviously acquire a very high velocity by the acceleration of gravity; and it consequently follows that the struggle between cohesion and gravity which takes place below the *vena contracta* of a descending stream cannot, from the shortness of its duration, be observed except by means of a rotating mirror, or by some other appliance for causing a body in motion to appear to the eye to be at rest. Plateau's column of oil can be readily observed to transform itself into isolated spheres; but the production of the thread and its subsequent contraction into a small sphere can only be observed by very close watching with the eye a short distance from the column. Experiments of this nature are therefore unsuited for the lecture table. I have, by modifying Plateau's experiment, reduced the velocity of a descending fluid to a minimum, so that the separation of a sphere, together with the intermediate thread and the sphere which it produces, can be readily shown as a lecture experiment.

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* "Hydraulic Researches," part 2, Poggendorff's *Annalen*, vol. cvi. Translated in the *Philosophical Magazine* for September 1859.

The mode of effecting this is, to cause the cohesion acting upon the particles of a fluid mass floating in a medium of nearly its own density to slightly preponderate over the gravitating force of the mass, and then, by slowly reducing the density of the medium, to allow gravity to act upon one portion of the mass.

A tall beaker was filled with a mixture of alcohol and water of the same density as oil: a quantity of oil was then introduced sufficient to form a sphere about 35 millimetres in diameter. When the sphere floated perfectly at rest in the centre of the medium, a small quantity of water was added, so as to render the medium slightly denser than the oil; the sphere now rose slowly to the surface, and assumed the form of a hemisphere with its plane surface in contact with the surface of the liquid. On gently warming the alcohol-and-water mixture, the hemisphere lengthened itself until it became a thick cylinder, hemispherical below, and with its upper end in contact with the liquid surface. Then it began to narrow at a point nearly midway between its opposite ends; and this continued until the cylinder was resolved into two masses of oil, separated by a narrow thread. A moment later the two masses suddenly contracted,—the upper one to a very convex plano-convex lens with its plane surface in contact with the liquid surface, the lower one to a nearly perfect sphere, which during its descent to the bottom of the beaker became slightly extended, alternately, at right angles to, and parallel with, the water-surface. The thread of oil, which had been drawn out by the weight of the lower mass, being no longer thus restrained, contracted into a small sphere floating midway between the separated masses of oil.

Perhaps a more effective mode of showing the experiment is the following. Prepare, as before, a mixture of alcohol and water; introduce a quantity of oil sufficient to form a sphere from 40 to 50 millims. in diameter, and let the density of the mixture be such that the sphere floats 20 or 30 millims. below the surface, the entire depth of the liquid being from 175 to 200 millims. On heating the mixture the sphere extends itself into an ellipsoid with its major axis at right angles to the liquid surface; it then gradually contracts at a point midway between the ends, until, as in the previous experiment, only a fine thread separates the two larger masses of oil; rupture then ensues, and the thread gathers itself into a sphere. The lower mass commences its descent as an ellipsoid having its major axis at right angles to the liquid surface, next becoming a sphere, then an ellipsoid with its major axis parallel with the liquid surface, once more a sphere, and so on until it reaches the bottom of the vessel, while the upper mass of oil ascends to the surface, and comes to rest as a hemisphere with its plane surface in contact with the surface of the liquid.

Let us consider the rationale of this experiment.

It is universally stated that when a mass of liquid is heated from beneath, the heat is conveyed to different parts by currents (a central ascending current of warm liquid, and descending side currents of cold liquid), by which means the whole mass of liquid soon becomes of a uniform temperature. Now, if the liquid in the above experiment rapidly acquired a uniform temperature, it is obvious that the lengthening of the oil-sphere into an ellipsoid and the transformation of the ellipsoid into isolated masses could not take place. For if the density of the liquid were uniformly lessened, the oil-sphere would descend *en masse*, and rupture could not ensue between its particles, because before the occurrence of rupture, gravity must act unequally upon the sphere; that is to say, the upper part must be competent, while the lower part is incompetent, to resist the action of the force. I was hence led to examine whether, under the conditions of the above experiment, the liquid *does* rapidly acquire a uniform temperature.

In the case of a homogeneous liquid, or of a uniform mixture, I found that the same temperature was rapidly acquired by all parts during heating from beneath. An oil-sphere placed in a perfectly uniform mixture, did not lengthen itself into an ellipsoid, but descended without change of form to the bottom of the beaker. The manner of trying the experiment described above was, to mix alcohol and water until the mixture possessed nearly the specific gravity of oil, then to introduce the oil, and to bring the oil-sphere to its desired position by pouring in alcohol. Now alcohol and water do not very readily mix, hence the upper layers of the liquid contained more alcohol than the lower layers ; and this accounts at once for the different temperatures observed, because the capacities for heat of alcohol and water differ considerably. It will be seen by the following results that, under the conditions of the above experiment, the alcohol-and-water mixture does not rapidly acquire a uniform temperature.

The mixture was placed in a beaker, and it occupied a depth of 175 millims. therein ; the beaker was placed upon a flat piece of copper heated by hot water. In order to measure the temperature, two thermometers, reading accurately together, were employed, and they were read by means of a lens. I was unable to detect any difference of temperature between the liquid near the sides of the vessel and that (in the same horizontal plane) in the centre ; neither did I find that the liquid soon acquired a uniform temperature. Thus, after heating for some time, the liquid near the top had a temperature of 19° C., that midway between the top and bottom of 23° C., and the liquid at the bottom of 40°·5 C. In another experiment, in which the heating had been continued for a longer time, the temperature was taken in successive intervals of space—the entire depth of the liquid (175 millims.) being divided into seven layers (as we may call them), each 25 millims. thick. The following were the temperatures, beginning at 25 millims. below the surface :—

First (uppermost) layer . . = 30° C.
Second layer . . . . = 30
Third ,, ... = 36
Fourth ,, ... = 44
Fifth ,, ... = 46
Sixth (lowermost) layer . . = 46

It is thus seen that a uniform temperature was by no means rapidly acquired throughout the liquid mass.

Now, at the commencement of the experiment described above (p. 51), the oil-sphere floats in static equilibrium; that is to say, it displaces a quantity of liquid precisely equal to its own weight, in a medium of uniform temperature. On heating the liquid, it soon happens that the layer in contact with the under surface of the oil-sphere becomes hotter, and consequently less dense, than the layer in which the upper part of the sphere floats; a part of the sphere is now surrounded by a medium of its own density, while the other part is surrounded by a medium of less than its own density. The densities, of the alcohol-and-water mixture and of the oil, do not decrease *pari passu* for equal increments of heat; and the oil does not receive heat so readily as the mixture, for it was sometimes found to be as much as 6° C. lower than the layer of liquid in which it floated. Gravity can now act upon the lower portion of the oil; and the consequence is that the sphere becomes an ellipsoid with its major axis in the direction of the force which has produced the change—that is to say, parallel to a plumbline. The upper part of the ellipsoid is still unacted upon by gravity, while the lower part has now reached a deeper and consequently warmer and less dense layer; hence gravity exercises greater force upon it; and there is nothing to resist this but the cohesion of the oil-particles. Contraction now commences at the point of greatest strain; and as gravity continues to predominate, rupture becomes more and more imminent. When this occurs, the lower mass, no longer restrained by the cohesion of the upper mass, and being now in a medium of less than its own density, sinks to the bottom; while the upper mass, having suffered a slight decrease of density by being dragged into a warmer layer by the lower mass, and being now liberated from that weight, is in a medium of greater density than its own, and consequently ascends to the surface.

It is obvious that the portion of this explanation which relates to the separation of the lower oil-mass applies equally to the experiment first described, in which the oil-mass, instead of floating in the medium, had its upper (plane) surface in contact with the liquid surface. I may remark, also, that while the former experiment takes about four minutes (from the commencement of heating), the experiment last described does not require more than one or two minutes. The latter experiment is most effective, and best suited for the lecture-table.

The following experiments would seem to prove the correctness of the explanation given above as to the cause of the lengthening of the oil-sphere into an ellipsoid, and its subsequent resolution into detached masses, under the conditions of the described experiment.

In order to ascertain the comparative rate at which the liquids employed in that experiment acquire a uniform temperature, a litre of each was heated for an hour, under precisely the same conditions, and the temperatures were observed at intervals of ten minutes. The beaker containing the liquid was placed upon a surface of sand (so that all parts of the bottom of the beaker might be uniformly heated) spread in a thin layer upon a copper plate heated by hot water. The temperatures were taken by means of two thermometers reading accurately together, one placed with the lower part of its bulb 3 millims. from the bottom of the beaker, and the other with the upper part of its bulb 3 millims. from the water-surface. The depth of the liquid column was 130 millims.

Distilled water and methylated alcohol were first tried separately. The temperature of the water was 6° C., and of the alcohol 6°·5 C., the specific gravity of the latter at that temperature being 0·830. The following results were obtained :—

Time of taking the temperature from the commencement of heating.	Water at 6° C.		Methylated alcohol at 6°·5 C.	
	Upper thermometer.	Lower thermometer.	Upper thermometer.	Lower thermometer.
Minutes				
10	11°·75 C.	12°·00 C.	16°·25 C.	16°·50 C.
20	17·00	17·50	23·25	23·50
30	21·25	22·50	28·50	29·00
40	25·00	26·25	32·00	32·50
50	28·50	30·00	34·75	35·25
60	31·25	32·50	36·50	37·25

It is seen from the above that a uniform temperature was very rapidly acquired by both liquids, the greatest difference in temperature between the uppermost and lowermost layers of water amounting to only 1°·50 C., and in the case of the alcohol to only 0°·75 C.

In making the experiment with the sphere of oil, it will be borne in mind that a mixture of alcohol and water was employed, and that the oil-sphere floating therein was brought to its desired position by pouring a small quantity of alcohol into the mixture as soon as the sphere had come to rest. It was therefore thought to be advisable to ascertain the rapidity with which the mixture acquires a uniform temperature, and to what extent this result is retarded by the addition of a known quantity of alcohol.

In order to determine this, a mixture was made of 500 cub. centims. of water at 4°·5 C. with 500 cub. centims. of methylated alcohol at 6° C. The resulting mixture (care being taken to make it perfectly uniform) was found to occupy a volume of 980 cub. centims., and to possess a temperature of 14°·25 C. It was allowed to cool down to 7° C., and then heated for an hour, under the same conditions which obtained when each liquid was heated separately, the temperatures being noted at similar intervals. At the end of the hour it was cooled to 7° C., and 50 cub. centims. of alcohol at 8° C. were poured in, and the heating recommenced. The added alcohol was coloured by means of a minute quantity of roseine, in order that the depth to which it penetrated might be observed. (It is needless to remark that the tinctorial power of roseine is so great that the amount added could not affect the accuracy of the experiment.) Although the alcohol was poured into the mixture (already containing half its bulk of that fluid) from a height of 40 or 50 millims., it showed no tendency to mix readily: the great bulk of it (as shown by the amount of colour) remained within 20 millims. of the surface, and the colour was observed to gradually shade off till at a depth of 55 millims. it disappeared; so that the 50 cub. centims. of added alcohol were entirely in the uppermost 55 millims. of liquid. The entire quantity of liquid now exceeded 1000 cub. centims., and its depth was 140 millims. The following results were obtained :—

Time of taking the temperature from the commencement of heating.	Alcohol-and-water mixture at 7° C.		Alcohol-and-water mixture at 7° C., with 50 cubic centims. of alcohol added.	
	Upper thermometer.	Lower thermometer.	Upper thermometer.	Lower thermometer.
Minutes				
10	15°·00 C.	15°·75 C.	9°·25 C.	19°·50 C.
20	20·50	21·25	12·00	26·75
30	25·75	26·50	20·00	32·00
40	30·00	31·00	26·00	35·00
50	33·75	34·50	30·25	39·00
60	36·00	36·75	34·50	41·00

It will be observed that the alcohol-and-water mixture acquired a uniform temperature as rapidly as either of its components heated alone, the greatest difference between the uppermost and lowermost layers of liquid amounting to only 1° C. But after the addition of the alcohol (although its quantity was less than one-twentieth of the total amount of liquid heated) a very different result is observed; for we find no less than 14°·75 C. difference of temperature between the uppermost and lowermost layers of liquid. The amount of heat, however, associated with the entire mass of each liquid at any given time during the heating is nearly the same, but it is differently distributed. If we take mean temperatures, we find that the greatest difference amounts to 1°·5 C.; but the approach is often much nearer, and in one case we have coincidence. Thus, at the end of forty minutes' heating, the temperatures of the uppermost and lowermost layers of the alcohol-and-water mixture were respectively 30° C. and 31° C.; and of the same mixture after the addition of the alcohol, 26° C. and 35° C.: we thus obtain the following means:—

$$\frac{30 + 31}{2} = 30^{\circ}\cdot 50 \text{ C.}, \frac{26 + 35}{2} = 30^{\circ}\cdot 50 \text{ C.}$$

The following Table shows the means for each time of observation:—

Time of taking the temperature from the commencement of heating.	Alcohol-and-water mixture.	Alcohol-and-water mixture, with added alcohol.
	Mean temperature.	Mean temperature.
Minutes.		
10	15°·375 C.	14°·375 C.
20	20·875	19·375
30	26·125	26·000
40	30·500	30·500
50	34·125	34·625
60	36·375	37·750

On continuing to heat the mixture containing the added alcohol, the upper layer in which it was present suddenly coalesced with the liquid beneath it, and the entire mass of liquid became at once of a uniform temperature. The lower thermometer stood at 42° C., and the upper one at 36° C., immediately before the coalescence.

It is seen from the above experiments that the addition of a small quantity of alcohol to a mixture of alcohol and water determines a very unequal acquirement of heat throughout the mass of that mixture during the process of slow heating from beneath. For, on account of the tardiness with which the added liquid mixes with the liquid to which it is added, the mass becomes divided into two distinct layers, the upper one containing more alcohol than the lower; and this latter receives almost all the heat communicated to the liquid, until, when a certain temperature has been attained, the two layers coalesce, uniformity of mixture and uniformity of temperature being simultaneously established throughout the mass.

We have, I conceive, in the above results the explanation of the cause of the change of the oil-sphere into an ellipsoid, and its subsequent transformations; for (as mentioned above) it is a necessary condition of this experiment that the fluid medium shall not during heating rapidly acquire a uniform temperature.

Experimental Illustration of Hydrodynamics.

The experimental illustrations of hydrodynamics are almost confined to the screw of Archimedes, the various forms of water-wheel, and to different forms of apparatus for showing the laws of efflux from horizontal and vertical orifices. The *vena contracta* may be shown by illuminating a descending jet by means of the electric light. Venturi's "lateral action" may be readily shown as a lecture experiment by various means, described by the Author in the *Philosophical Magazine* for February 1867 ("*On some Effects produced by a Fluid in Motion*"). Thus the lateral action of a moving gas may be seen by suspending a thin bulb of glass in a vertically effluent jet of steam; or by the approach of two disks facing each other, by directing a jet of air through the centre of one of them, so that it strikes the other; or, again, by the collapse of a partially open sheet of paper, by blowing a current of air between the opposite leaves. In the case of a liquid, if a rapid jet of water be delivered parallel to, and just beneath, the surface of water, air will force itself through the water into the axis of the jet (where the motion being greatest the pressure is least), and will be carried along by the jet. Or if a jet be allowed to flow near a sphere of oil floating in static equilibrium in a medium of its own density, the sphere will become an ellipsoid, with its major axis at right angles to the direction of the influent jet.

PNEUMATICS.

147. The science of *Pneumatics* treats of forces, or pressures, which either are, or are not, in equilibrium, and which therefore produce conditions either of rest, or of motion, as the case may be, in gases. (Πνεῦμα, breath, wind; from πνέω, to breathe, blow. There are not separate sciences of Pneumastatics and Pneumadynamics, as in the case of the mechanics of solids and liquids.)

148. Gases are extremely elastic bodies, and are hence sometimes termed *elastic fluids*; but the term is inappropriate, because ordinary fluids are also elastic, although to a far less extent (N. 117).

149. The term *gas* (allied to the German *geist*, a spirit, and to our word *ghost*) is used to signify a substance whose constituent molecules are uninfluenced by cohesion (N. 13), and which hence vibrate unrestrictedly with the motion called heat (N. 225). A *permanent gas* is a gas which has resisted all efforts to liquefy it (N. 233), such as oxygen, nitrogen, hydrogen. A *condensable gas* is a gas which is more or less distant from its point of condensation, but which can be condensed by mechanical or physical means—viz. by pressure, or by the withdrawal of molecular motion; such as carbonic anhydride, ammonia, chlorine. A *vapour* is the gas of a substance which ordinarily exists in the liquid form, but which assumes the gaseous form by the addition of molecular motion, or by a diminution of pressure; such as vapour of ether, steam,

vapour of mercury. (*Vapor*, steam, allied to *κάπω*, and to the Sanskrit *vâ*, to blow.)

150. Air, although a mixture of permanent gases, acts, and is acted upon, physically, in all respects like an elementary permanent gas; it is consequently taken as the type of gaseous bodies.

151. Gases, although intangible, and often invisible matter, may be proved to possess impenetrability (N. 8), inertia (N. 12), and weight (N. 27), like more palpable forms of matter. The impenetrability of air may be shown by depressing a tumbler, mouth downwards, into a vessel of water, when it may be noticed that the water does not enter, because as air is matter, it is obvious water and air cannot occupy the same space at the same time. The inertia of air is proved by the resistance it offers to a body moved quickly through it, and by its momentum in wind, which is simply air in motion. The weight of air can be demonstrated by weighing a vessel full of air, then pumping out the air and weighing again.

152. The weight or pressure of the air may also be shown by the *Barometer* (*βάρος*, weight, *μέτρεω*, to measure), an instrument devised by Torricelli in 1644. It was well known that water would rise in a pump, and this was said to be due to Nature's abhorrence of a vacuum. But when Galileo noticed that the water would only rise to a height of about 33 feet, another explanation had to be sought, and Torricelli conceived that the effect was due to the upward pressure of the atmosphere. Accordingly, he filled a tube, closed at one end, with mercury, the densest liquid—as a tube of water is eminently inconvenient, from its length—closed the open end with his finger, and inverted the

tube with its now open end in mercury. The mercury in the tube fell to a height of about 30 inches above the mercury in the basin beneath, and this column of mercury he rightly inferred to be balanced by the external pressure of the atmosphere. Such an instrument (Fig. 11) constitutes a barometer. The truth of Torricelli's conjecture was proved by Pascal, who carried a barometer to the summit of a mountain, and found that the higher he ascended the lower did the mercury sink, because the column of air supporting it was likewise shortened, and thus exerted less pressure.

153. The space above the mercury in a barometer is a nearly perfect vacuum, containing only a trace of mercury vapour. This is known as the *Torricellian Vacuum.*

154. A *vacuum* (*vacuus*, empty) is a space devoid of all matter recognisable by any means, direct or indirect, physical or chemical. It contains indeed only that subtle form of matter called the interstellar medium, or luminiferous ether (N. 170); otherwise a vacuum would be dark (N. 169), and would refuse to permit radiant heat to cross it (N. 258).

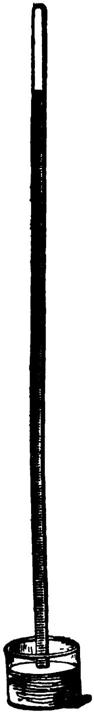


Fig. 11.

155. A *water-barometer* may be constructed; it contains a column of water 33 feet high, and as water is far more volatile than mercury, the space above the column is a far less perfect vacuum than the Torricellian vacuum, and contains aqueous vapour which exercises a very appreciable tension.

156. The average pressure of the atmosphere (*ατμος*, vapour, *σφαῖρα*, a sphere) is 15 lbs. on the square inch of surface; hence a column of mercury 30 inches high, and a column of water 33 feet high, and in both instances of one square inch of sectional area, weigh respectively 15 lbs.

157. An *atmosphere of pressure* signifies a pressure of 15 lbs. on the square inch of surface; or, more exactly, a pressure of 29·96 inches, or 760 millimetres, of mercury.

158. Gases obey Pascal's law of liquid pressure (N. 118), that is to say, they transmit pressures equally in all directions. Hence a body is pressed upon in every direction by the atmosphere, and if the pressure be not exerted in opposite directions, the object may be crushed. Thus by exhausting the air from thin glass or metal vessels they are crushed by the outward atmospheric pressure. A thin open glass vessel is not crushed, because the atmosphere presses inside and outside with equal and opposite force. Again, our bodies would be crushed by a weight of about 15 tons (taking the extent of external surface as 2000 square inches), if this pressure were not neutralised by equal and opposite internal pressure.

159. Gases are eminently elastic. They may readily be compressed by increase of pressure, and caused to expand by diminution of pressure, or by an increase of molecular motion (N. 229, 230). The volume of a gas at a constant temperature is found to vary inversely as the pressure to which the gas is submitted. Thus, if the pressure be doubled, the volume of the gas is reduced to one-half; if the pressure be trebled, the volume is reduced to one-third; and so on. This

is known as *Boyle's Law.* Again, if the pressure be halved, the volume of the gas is doubled. If V = the observed volume of a gas under a given pressure p, and V' the volume to be determined, under a given pressure p', then

$$V'p' = Vp$$

$$\text{or } V' = \frac{Vp}{p'}.$$

The normal pressure to which gases are reduced is 29·96 inches, or 760 millimetres, of mercury. If we have 500 cubic centimetres of gas existing under a pressure of 450 mm. of mercury, and desire to know its volume at the normal pressure, we readily find it by the use of the above formula: for

$$V = \frac{500 \times 450}{760} = 282{\cdot}8 \text{ cc.}$$

Boyle's law may readily be proved by the use of the tube shown in Fig. 12. A known volume of gas is confined in the shorter closed limb of the instrument, and it is submitted to various pressures by pouring mercury into the longer limb. Both limbs are graduated. The reduced volume of gas, and the height of the column of mercury which has produced the reduction of volume, may thus be read off, and compared.

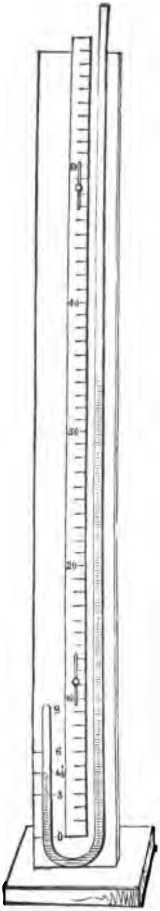


Fig. 12.

160. It follows also, from Boyle's law, that, at a constant temperature,

the density of a gas is proportional to the pressure to which it is submitted. Thus, water is about 780 times as heavy as air, and mercury 10,800 times, bulk for bulk; hence under a pressure of 780 atmospheres (N. 157) air would be as dense as water, and under a pressure of 10,800 atmospheres it would be as dense as mercury.

161. The law of Archimedes applies to gases. A balloon rises because the weight of air which it displaces is greater than the weight of gas which it contains, *plus* the weight of the material of the balloon. Hence, also, we never obtain the absolute weight of anything unless it be weighed in a vacuum; for the observed weight of a body weighed in air will obviously be its real weight *minus* the weight of the air which it displaces (N. 129).

162. The *air-pump* is an instrument for pumping air out of a closed vessel. It consists, in principle, of

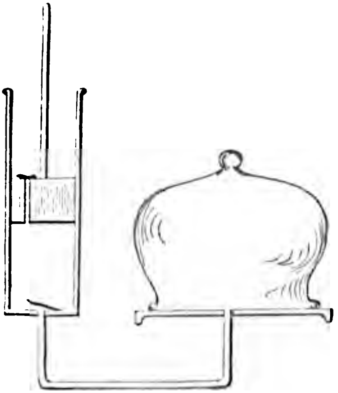


Fig. 13.

a metallic cylinder in connection with the vessel to be exhausted, and fitted with an air-tight piston. The lower part of the cylinder, and also the piston, are each furnished with a valve (*valva*, a folding door) opening upwards (Fig. 13). Suppose the piston to be at the bottom of the cylinder; on raising it a vacuum is left beneath it, and the elasticity of the air in the vessel to be exhausted causes it to rush into the vacuous space, thereby opening the valve in the cylinder. On depressing the piston the latter valve is closed, the air enclosed between the bottom of the cylinder and the piston opens the valve in the latter and escapes; and the next stroke takes place in the same manner.

163. The *water-pump* is precisely the same as the air-pump in principle. The vessel to be exhausted is replaced by the well, or vessel containing water, and the water is caused to ascend into the vacuum by the downward pressure of the air upon it. If A B (Fig. 14) represents the pump-barrel, E represents the barrel-valve opening upwards, and C the valve of the piston also opening upwards.

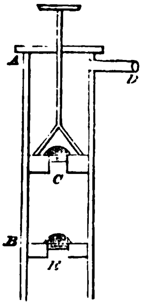


Fig. 14.

164. The *siphon* (from an oriental word *sif*, signifying to draw out with the breath, hence also *sip*) consists of a bent V-shaped tube, open at both ends, and having one limb longer than the other. It is employed for transferring liquids from a higher to a lower level. In order to effect this, the tube is filled with the liquid, inverted, and the shorter limb is immersed in the vessel at the higher level. The liquid then flows continuously, until the level is the

same in both vessels. This arises from the fact that the pressure on the liquid at the orifice of the shorter limb of the siphon is greater than the pressure at the orifice of the longer limb, by the height of a column of liquid equal to the difference between the lengths of the two limbs. Thus (Fig. 15) the pressure on A is greater than the pressure on C by the difference in the length of A B and B C.

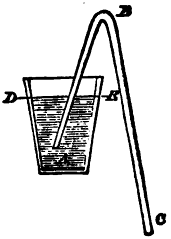


Fig. 15.

Experimental Illustration of Pneumatics.

The apparatus required for the illustration of this science cannot be improvised, or constructed by other than skilled workmen. A good air-pump is indispensable; the metallic parts must be of compact carefully prepared metal, and the pump plate and receivers must be accurately and exquisitely ground. The Magdeburg hemispheres furnish a very effective experiment. The weight of air may be shown, by a fairly sensitive lecture-balance, by means of a globe of glass furnished with a stopcock, into which air can be forced by a condensing syringe, or from which air can be exhausted by an air-pump. Torricelli's experiment is, of course, most important. The tube should be about 90 centimetres long, and have an internal diameter of one centimetre. The gradual subsidence of the column of mercury as the pressure diminishes, when the cistern into which the tube dips is placed beneath the air-pump receiver, is an important and striking experiment. Boyle's law should be strictly demonstrated, if practicable, to three atmospheres. Good working models of pumps in glass are now constructed in Germany at a reasonable rate; they are furnished with conical valves of ground black glass, the action of which is perfectly seen during the working of the pump. Siphons may be readily constructed out of ordinary glass tubing.

LIGHT.

165. The term *light* is derived from the Anglo-Saxon *lyht*, related to the German *licht*, Gothic *liuhath*, Latin *lux*, Sanskrit *lôc*, to see, and *rúc* to shine.

166. We apply the term *light* to a peculiar form of motion transmitted by the interstellar medium, which motion, when communicated to the brain by the optic nerve, produces the sensation of vision. (Compare N. 202, 203.)

167. Two theories have been proposed in order to explain the nature of light, known respectively as the *Emission* or *Corpuscular theory*, and the *Undulatory* or *Wave* theory. (Compare the Material and Kinetic theories of Heat: N. 202, 205, 206.)

168. The Emission Theory asserts that light consists of extremely minute particles of matter which issue from luminous bodies, and are translated through space with extreme velocity, producing vision by impact against the retina. This theory, although it received the support of Newton, is no longer accepted.

169. The *Undulatory Theory* (*unda*, a wave) asserts that luminous bodies are in a state of rapid vibration, and that they transmit the motion of their oscillating particles by means of the interstellar medium (or *luminiferous ether*, as it is sometimes called). This theory is now universally accepted.

170. The interstellar medium, or ether, is an infinitely subtle form of matter, many cubic miles of

which would not weigh a grain. It fills space, and is capable of penetrating the most dense substances: indeed the atoms of all bodies are bathed in the ether. It accepts vibratory motion from luminous bodies, and transmits it in all directions in the form of spherical waves. When these waves dash upon the retina they impress us with the sensation of vision.

171. The term *ray* is used to designate the direction in which light travels. Light travels in straight lines in a homogeneous medium, but changes its direction when it encounters an object which cannot assimilate its motion (N. 182, 183), and when it passes from one transparent medium to another (N. 190).

172. When light is emitted from a luminous point, a divergent cone of rays, sometimes called a *pencil of rays*, is produced, as shown in Fig. 16. But if the source of light be very distant, the rays become practically parallel, as in Fig. 17, and are then spoken of as a *sheaf of rays.*

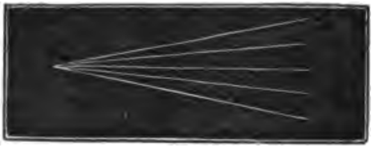


Fig. 16.

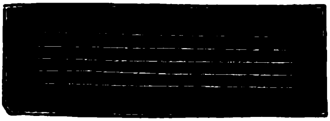


Fig. 17.

173. The particles of ether oscillate at right angles to the direction in which the light travels. In other words the vibrations of the ether are *transversal*, not longitudinal (compare N. 260).

174. By the synonymous terms *vibration*, *oscillation*, *undulation*, we are to understand alternating movements across a position of rest. We may take as examples (α) a pendulum, or the agitated string of a violin; (β) the waves produced when a stone is thrown into water; (γ) the aërial waves produced by a chiming bell, or other sounding body.

175. We may roughly figure to ourselves the vibrations of the luminiferous ether, by attaching one end of a long cord to a firm support, while we hold the free end in our hand. If we now jerk the cord, a wave is seen to travel to the fixed end, to be there reflected, to return, and so to travel backwards and forwards until it is spent. Our hand here takes the place of a luminous body, while the cord becomes a row of ether particles. It is obvious that any particle in the cord moves, during the transmission of the motion, at right angles to the direction in which the wave is propagated.

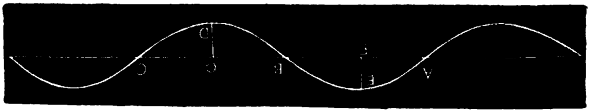


Fig. 18.

Thus let A B C represent a single wave-length; A B and B C will represent half wave-lengths; E F the height, and C D the depth of the wave. A particle situated at E, or anywhere along the curve of the wave, will clearly move at right angles to the straight line, indicating the direction of propagation of the wave.

176. *Luminous bodies* are those which generate vibratory motion, and transmit it to the luminiferous ether; such are the sun, a piece of burning phosphorus, and an incandescent coal.

177. *Illuminated bodies* are those which receive vibratory motion from luminous bodies, and reflect it from their surfaces to our eyes, thus rendering themselves visible. Thus the objects in a room are rendered visible by a candle flame, but if that flame be screened or covered by an opaque substance they cease to be visible, because they had before shone with borrowed light, and possess none of their own.

178. *Transparent bodies* (*trans*, through; *pareo*, to appear) permit light to pass through them. Many crystals, glass, water, gases, are examples.

179. *Opaque bodies* (*opacus*, dark, obscure) do not permit light to pass through them. Such are wood and metals.

180. The intensity of light diminishes as the square of the distance increases; or otherwise, the intensity of illumination of an object is inversely as the square of the distance of that object from the source of light. Thus, if the distance be doubled, the intensity is reduced to *one-fourth;* if it be trebled, the intensity is reduced to *one-ninth*. Or more generally, if the distances are—

$$1,\ 2,\ 3,\ 4,\ 5\ \ldots\ldots\ n,$$

the intensities will be

$$1, \frac{1}{4}, \frac{1}{9}, \frac{1}{16}, \frac{1}{25}, \ldots\ldots \frac{1}{n^2}$$

181. The velocity of light, according to Roemer, is 192,500 miles per second; according to Bradley, 191,515 miles.

182. Light is *reflected irregularly*, or scattered, from the surface of imperfectly polished bodies.

183. Light is *reflected regularly* from smooth polished surfaces. Such surfaces, which are sometimes plane and sometimes curved, are called *mirrors* (*miror*, to wonder at), or *specula* (*specio*, to look).

184. When light is reflected from a polished surface, if it be perpendicular thereto, it is reflected back, along the path whence it came. But if the ray be oblique to the surface, it is reflected obliquely, and the angle of incidence is equal to the angle of reflection, and in the same plane.

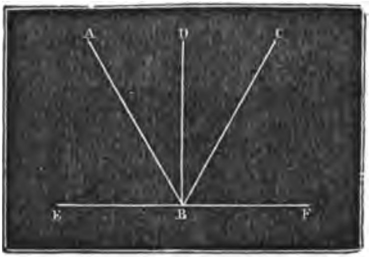


Fig. 19.

Thus if a ray of light D B be incident upon a surface E F, it will be reflected back along the same line; but an oblique ray A B will, after striking the surface, be reflected along the line B C; and the angle A B D will be equal to the angle C B D.

185. In plane mirrors the image of any object re-

flected, appears to be as far behind the mirror as the object is in front of the mirror. If a line be drawn from the object at right angles to the mirror and be produced, the image will apparently lie upon that line, at the point where a line drawn from the eye of the observer through the point of reflection, intersects it.

186. The reflection of light from curved surfaces follows the law as to the equality of the angle of incidence and of reflection (N. 184). We may imagine any curved surface to be formed by a number of small plane surfaces. In a spherical concave mirror the reflected rays meet at a certain point in front of the mirror called the *focus* (*focus*, a hearth). The *principal focus* of a mirror is a point midway between the centre of curvature of the mirror and the mirror itself, to which all incident rays (supposing them to come from a distant source, and hence to be practically parallel) converge.

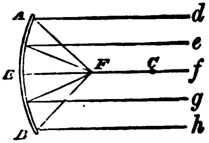


Fig. 20.

Thus if A E B be a mirror, and C its centre of curvature, F will be its focus for the parallel rays d e f g h.

187. If the luminous source be placed between the principal focus and the mirror, the rays after reflexion no longer converge to the *real focus*, but diverge; and if their rays are continued on the other side of the mirror they meet at a point, and form a *virtual focus*.

188. Convex mirrors only possess virtual foci; rays reflected from their surfaces can never be brought to a point in front of the mirror.

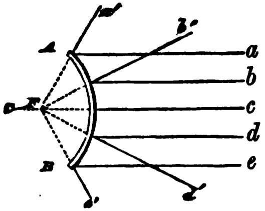


Fig. 21.

Thus the rays a b c d e, which, if prolonged, would meet at the virtual focus F behind the convex mirror A B, are reflected along the lines Fa′, Fb′, Fd′, Fe′.

189. When light falls upon a transparent substance it undergoes various changes; for (α) a portion of it is regularly reflected according to the manner indicated above, producing an image of the object from which the light proceeds (N. 183); (β) a portion of it is irregularly reflected (N. 182), and the surface of the substance is thus rendered visible; (γ) a portion is absorbed by the substance; and (δ) a portion is transmitted through the substance.

190. When light passes obliquely from one transparent medium to another of different density, it is bent aside from its direction of incidence. This is known as the *refraction* of light (compare N. 266). Refraction appears to be due to the relative velocity of the ether waves in the two substances.

Thus the ray E, if it passes from a rarer medium into a denser medium bounded by the line B A, will be refracted along the line D F, instead of continuing its course in the direction E D.

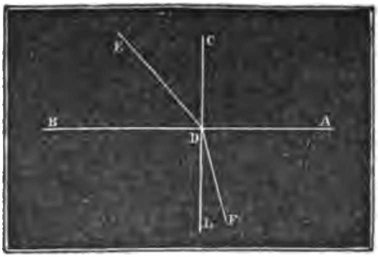


Fig. 22.

191. Descartes' law asserts: (α) that the angles of incidence and of refraction are in the same plane,

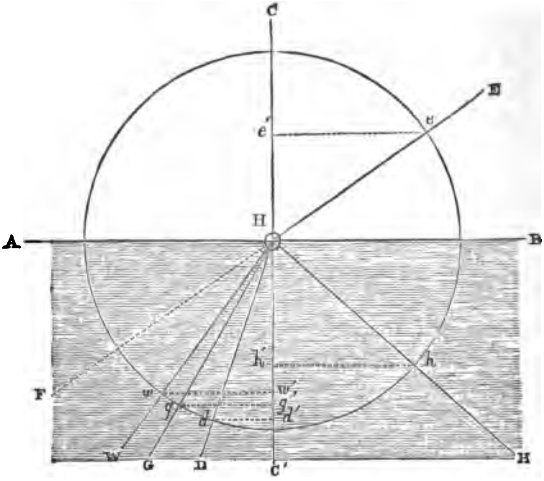


Fig. 23.

which plane is at right angles to the refracting surface; and (β) that the sine of the angle of incidence bears a ratio to the sine of the angle of refraction, which is constant for the same medium. This constant ratio is the ratio of the velocities of propagation of the waves of ether in the two substances.

Thus if E H represent a ray of light passing from a rarer medium into a denser medium, the surface of which is bounded by the line A B, it will be bent towards the perpendicular C C′ to an extent varying with the density of the medium, as HW, HG, HD, and the sine e′ e of the angle of incidence E H C will bear a constant ratio to the sine d d′ of the angle of refraction D H C′, or whatever that sine may be for another refracting medium, as gg′, ww′. Descartes' account of this law will be found in his *Dioptrices*, cap. 1.

192. The *index of refraction* of a substance, represented by μ, is found by dividing the sine of the angle of incidence by the sine of the angle of refraction. If v denote the velocity of the wave in the medium from which it enters the refracting medium, and v' the velocity of the wave in the refracting medium; and if the angle of incidence be denoted by i, and the angle of refraction by r, then—

$$\frac{v}{v'} = \frac{\sin i}{\sin r}$$

Hence $$\mu = \frac{v}{v'} = \frac{\sin i}{\sin r}$$

The following are the indices of refraction of a few substances:—

Chromate of lead	2·97	Rock crystal	1·547
Diamond	2·47	Plate glass	1·542
Sulphur	2·11	Ice	1·315

193. Transparent substances possessing curved surfaces are called *lenses* (*lens*, a lentil-seed). According to their form they cause incident rays to converge, or to diverge, after suffering refraction by passing through their substance. Fig. 24 shows various lenses in section; their axis is the line A, B. The lenses C, D, F, and H, are convergent, the others divergent.

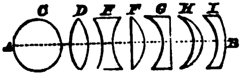


Fig. 24.

194. A solid transparent substance having two plane faces inclined to each other is called in optics a *prism* (πρίσμα, lit. that which is sawn, from πρίω, to saw). A ray of light which passes through such an instrument is permanently refracted.

195. By means of the prism Newton proved that a beam of sunlight consists of a great number of rays possessing different refrangibilities.

196. Light is thus said to be *analysed*, or *decomposed*, by the prism. The process of decomposition, or separation of the different constituents of white

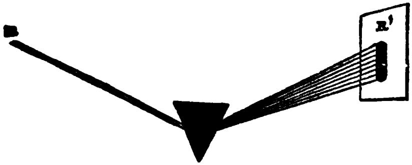


Fig. 25.

light, is called *dispersion;* and the luminous band of seven colours which results is called the *spectrum.*

197. The spectrum is terminated at one end by red light, at the other by violet light. The sensation of red is produced by the assumption of 477,000,000,000,000 impulses by the optic nerve per second, and the sensation of violet by 699,000,000,000,000 impulses.

198. The *Camera Obscura* is a dark chamber, with an aperture, in one side, in which is fixed a double convex lens. If a sheet of paper be placed within the chamber and opposite the lens, an inverted image of external objects is seen upon the paper. The inversion of an object by a double convex lens is shown in Fig. 26.

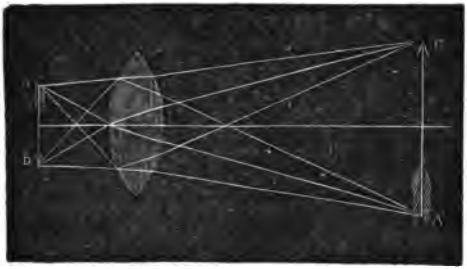


Fig. 26.

199. The eye is a camera obscura, having a double convex lens in front, the inverted image formed by which falls upon a delicate network of nerve-fibre, which directly communicates with the brain by means of the optic nerve, and transmutes external effects into impressions capable of being recognised by the brain.

200. We see substances distinctly at very different distances from our eyes. The eye can adjust itself to such distances by changing the curvature of its lens, the convexity increasing for near vision, and diminishing for distant vision. Fig. 27 represents the lens of the eye, with different curvatures produced by the contraction of the ciliary muscles *s s.* The curvature for distant objects is shown by *m*, and for near objects by *n*.

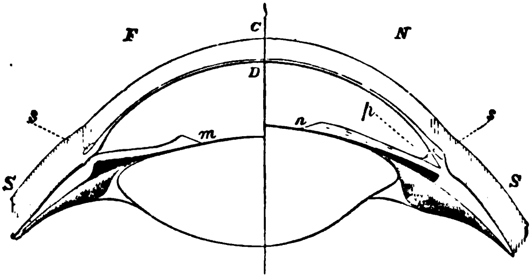


Fig. 27.

Experimental Illustration of Light.

The subject of light can only be illustrated by means of diagrams, unless a dark room, and an electric, oxy-hydrogen or magnesium lamp can be provided. If this arrangement be possible, the experiments are very varied, and all the properties of light may be demonstrated more or less completely. Good lenses of various forms, mirrors both plane and curved, and several prisms (one of which should be filled with the purest bisulphide of carbon), will be found the most needful apparatus. If the demonstrations are not required for lectures, but for private work, the sun may be used as the source of light. A circular hole in the window-shutter of a dark room will admit a ray of sunlight, which may be rendered horizontal by means of an inclined mirror, and may then be employed to illustrate reflection, refraction, and dispersion.

The earlier experimenters on light invariably used the sun as their source. Hence lectures on optics were often (from the difficulties of darkening a room, and the frequent impossibility of having the sun at the right moment) altogether unillustrated, except by diagrams and black-board drawings. They thus became more like mathematical lectures, than lectures on experimental science. We are scarcely surprised, therefore, to hear that a notable University once counted among her Professors a blind Professor of Optics. That the subject is capable of considerable experimental illustration, was proved long ago by S'Gravesande, who was the author of the first text-book on Natural Philosophy which pretended to any degree of completeness. This was the *Physices Elementa Mathematica Experimentis confirmata*, first published in 1720; and which in 1743 had reached a third edition, *duplo auctior*. S'Gravesande devotes no less than 234 quarto pages to the subject of light; and by many really admirable copper-plates he has indicated a complete experimental treatment of the subject,—as complete at least as was then possible.

HEAT.

201. The term *Heat* is derived, according to Bopp, from the Sanskrit root *indh*, to kindle, through the Greek *αιθω*, the Latin *æstus*, the old High German *eit*. "Æstus," says Vossius, "est commotio . . . omnis commotio fervorem gignit."

202. The term is perfectly appropriate, for heat is believed to be a rapid motion of the minute invisible particles, or *molecules*, of matter. (Molecule from *molecula*, literally a little mass, a low Latin diminutive of *moles*, a mass, used to express a mass of infinitesimal minuteness.)

203. This motion, when transmitted to the brain by the molecules of the cerebro-spinal nerves, produces in us the sensation by which heat is familiarly recognised and known.

204. The idea of motion has been associated with that of heat from the earliest times; somewhat definitely by Zeno, Epicurus, and Lucretius. Also by Cardanus, Telesius of Cosenza, Francis Bacon, Descartes, John Locke, and numerous writers of the sixteenth and seventeenth centuries.

205. Towards the close of the seventeenth century there arose a theory which was based upon the supposed existence of a subtile matter, called "*materia aut principium ignis non ipse ignis*" (otherwise called the Theory of Phlogiston, from *φλογιζω*, to kindle).

206. During the eighteenth and far into the present

century a Material theory of heat was almost universally adopted, in place of the older but less definite kinetic theory (κίνησις, motion).

207. In 1798 Count Rumford showed the fallacy of the material theory by demonstrating the unlimited production of heat by friction, and the falsity of the explanation offered by the Materialists to the effect that this heat arose from an altered capacity for heat in the substances submitted to friction.

208. A few years afterwards Sir Humphrey Davy conclusively proved the immateriality of heat, by melting ice by friction in a vacuum at a freezing temperature, it being admitted even by the Materialists that water at 0° C. possesses more heat than ice at 0° C.

209. It was not, however, until the determination of the relationship between the unit of mechanical work and the unit of heat (called the "*mechanical equivalent of heat*") by Dr. Julius Mayer and Mr. Joule, independently of each other, about the year 1842, that the material theory of heat was finally abandoned.

210. In this country the *Unit of heat* is that quantity of heat necessary to raise 1 lb. of water through 1° Fahr.—strictly from 55° to 56° Fahr. On the Continent the unit of heat is that quantity of heat necessary to raise 1 kilogramme of water through 1° C—strictly from 0° C. to 1° C.

211. The *mechanical equivalemt of heat* is the amount of mass motion equivalent to, and convertible into, a definite amount of molecular motion, or heat. It is expressed as the distance through which

1 lb. of water must fall under the influence of gravity, in order to acquire a rise of temperature of 1° Fahr. when its motion is stopped. This distance, according to Mayer, is 771·4 feet; and according to Joule 772 feet. Thus, 1 lb. falling from a height

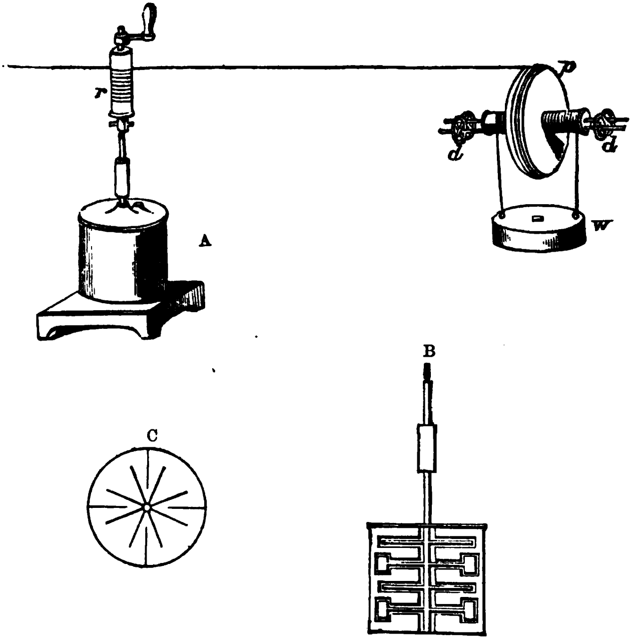


Fig. 28.

of 772 feet generates by its collision with the earth a sufficient amount of heat to raise 1 lb. of water 1° Fahr.; and conversely the amount of heat necessary to raise the temperature of 1 lb. of water 1° Fahr. would, if mechanically utilised, lift 1 lb. to a height of 772 feet above the surface of the earth, or 772 lbs. to a height of 1 foot. Hence 772 foot-pounds (or 424 kilogram-metres) represent the mechanical equivalent of heat (N. 79).

Fig. 28 represents the apparatus employed by Mr. Joule for the determination of the relationship between heat and mechanical work. A cylindrical vessel A (shown respectively in horizontal and vertical section in B and C) is fitted with a paddle, to which rapid rotatory motion can be given by the falling weight W, which rests upon friction wheels *dd*, and gives motion to the axis of the paddle by rapidly unwinding string from *r* during its descent. At the end of each descent the weight can be wound up again (without turning the paddle), and is again released. The weight W, the laws of falling bodies, the distance through which W falls, the amount of water in A, the rise of temperature, after a certain amount of agitation by the rotating paddle, and the specific heat (N. 255) of the water, and of the materials of the instrument, furnish data from which the mechanical equivalent of heat can be readily determined.

212. The *sources of heat* may be divided into—(α) Extra-terrestrial; (β) Terrestrial; and (γ) Intra-terrestrial. The last are unimportant.

213. The extra-terrestrial sources are the sun, moon, and stars. The total amount of heat received by the earth from the sun in one year (including that absorbed by the earth's atmosphere) would melt a stratum of ice 105 feet (32·01 metres) in thickness surrounding the entire earth.

214. The terrestrial sources are — (α) mechanical actions, such as friction; (β) chemical actions, such

as the combustion of coal; (γ) electrical actions, such as the passage of electricity through a thin wire of badly-conducting substance.

215. Kinetic energy (N. 105) is readily transformed into heat. Friction, percussion, compression, and the partial or complete stoppage of motion in any form, and by any means whatsoever, afford examples of this.

216. The amount of heat (H) produced by the stoppage of a moving mass is equal to the mass (m) of the moving body, multiplied by the square of its velocity (v). That is—

$$H = mv^2$$

Thus, if the velocity of a projectile be doubled, the heat produced by the stoppage of its motion by friction or collision will be quadrupled.

217. The production of heat by chemical action is probably due to the destruction of the kinetic energy of the molecules, when they rush together in the act of union under the influence of chemical affinity.

218. The production of heat by the energy of electricity in motion cannot be accounted for until more is known of the nature of electricity. (Possibly, in the experiment of transmitting an electric current by a thin wire of badly-conducting substance, the electricity so agitates the molecules of the conducting wire, that while communicating its own motion, a collision of molecules results, and a consequent production of heat. That is to say, the electricity may indirectly confer kinetic energy upon the molecules of the conducting wire, which energy is resolved into heat.)

219. The converse of the above actions also takes place: thus heat is consumed (α) in the perfor-

mance of mechanical work, as in the steam-engine; (β) in the separation of molecules united by chemical affinity, as in the blast furnace; (γ) in the production of electricity in motion, as in the thermo-electric pile.

220. "*Æstus est commotio . . . omnis commotio fervorem gignit.*" Heat having been defined as a motion of the small particles, or molecules, of matter, it is obvious that the addition of this motion to a congeries of molecules must cause them to occupy a greater space than before. (*Expansion*, *ex*, out, and *pando*, to spread, or open.)

221. On the other hand, the subtraction of this motion must cause the molecules to approach nearer to each other, and thus to occupy a lesser space than before. (*Contraction*, *contraho*, to draw or bring together.

222. In virtue of these actions heat determines the form which matter assumes.

223. In *Solids* the attraction of the molecules for each other (called *cohesion*, from *cohæreo* to stick together, N. 13), greatly predominates over the molecular motion, and, by limiting the range of movement of the molecules, keeps them comparatively close together.

224. In *Liquids* there is a greater amount of the molecular motion; hence the range of movement of the molecules is extended, the cohesive force is lessened by the distance, and the molecules have a less restrained motion.

225. In *Gases* there is a still greater amount of molecular motion; the molecules move at such a dis-

tance from each other that their individual attraction becomes a vanishing force: hence they are absolutely unrestrained in their motion.

226. Thus in the passage from solidity to gaseity there is a progressive decrease of cohesive force arising from a progressive augmentation of the space between the attracting molecules; and a progressive increase of molecular motion, arising from direct addition; while in the passage from gaseity to solidity there is a progressive increase of cohesive force arising from a diminution of the space between the attracting molecules, and a progressive decrease of molecular motion arising from direct transference.

227. The *co-efficient of expansion*,—linear, superficial, or cubical,—is the increase in length, surface, or volume of a substance, for 1° of temperature, whose length, surface, or volume at a given temperature (generally 0° C.) is taken at unity.

228. Let us inquire the difference in the length of an iron railroad, say between London and Edinburgh, in winter and summer. The co-efficient of linear expansion of iron for 1° F. is 0·00000686; the extremes of summer and winter temperatures at least 70° F.; the distance between London and Edinburgh about 400 miles. From these data we calculate that the rails are 338 yards longer upon a warm summer's day than during a severe frost.

229. The extent to which solids and liquids expand for a given increment of heat is dependent to a great extent upon the intensity of the attractive force associated with their molecules (N. 223); and as this varies with the substance so does the co-efficient of

expansion. But in gases (N. 225) the molecules are not sufficiently near to each other to allow the exercise of cohesion (which is a force acting through an insensible space), hence gases are equally affected by an equal increment of heat.

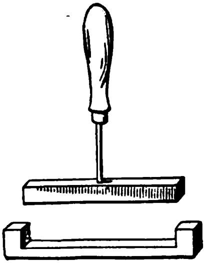


Fig. 29.

There are various means of showing the expansion of a solid. Thus in Fig. 29 the bar will fit into the groove when cold, but on heating can no longer be made to fit. The expansion of a liquid is illustrated by any form of liquid thermometer, and of a gas by any form of air thermometer.

230. All gases which are far from their point of liquefaction expand $\frac{1}{273}$ of their volume at 0° C. for 1° C., and $\frac{1}{490}$ of their volume for 1° F. Thus a gas at 0° C. will double its volume if raised to 273° C.

231. The superficial expansion of a substance is equal to twice its linear expansion, and the cubical expansion to three times the linear. Thus the co-efficient of superficial expansion of iron for 1° F. is 0·00001372, and the co-efficient of cubical expansion for 1° F. is 0·00002058.

232. If we require to know the volume of a gas at 0° C., which is occupying a known volume at some higher temperature, we readily find it by the following expression, in which V is the volume at 0° C.; *v* the observed volume at t° temperature. Then:—

$$V = v - \frac{vt^\circ}{273}$$

233. An increase of external pressure tends to approximate the molecules of matter, and hence *à priori* to some extent produces the same result as a subtraction of molecular motion; while a decrease of external pressure affords the molecules a greater range of movement, and hence produces the same

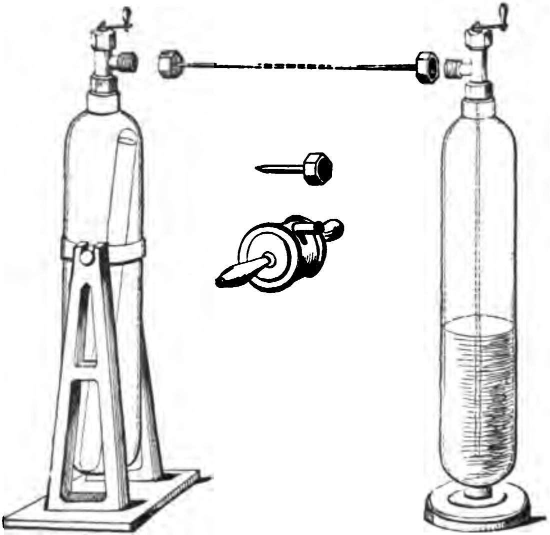


Fig. 30.

result as an addition of molecular motion. Thus certain gases are liquefied by increased pressure, and certain liquids are gasified by the removal of the existing pressure.

The apparatus shown in Fig. 30 is often employed for liquefying carbonic anhydride. The gas is generated in the left-hand vessel by the decomposition of bicarbonate of sodium by sulphuric acid; and is condensed in the second vessel by its own pressure. Between the two vessels is seen an appliance for collecting the solidified carbonic anhydride, which is produced by the rapid evaporation of the escaping liquid, and consequent consumption of heat.

234. We do not know the nature of the motion which constitutes heat. According to an hypothesis which is ably supported, the molecules of solids and liquids move circularly around a centre, while the molecules of gases move in right lines. Thus a solid becomes a liquid when the amplitude of the oscillation of its molecules passes a certain limit, and a liquid becomes a gas when its molecules fly off at a tangent to the circles in which they previously moved.

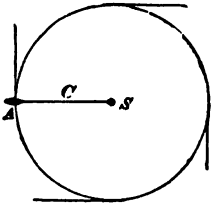


Fig. 31.

This may be illustrated by causing a body *A* to revolve about on centre S, retaining it in its place by a string, C (representing the force of cohesion). If now the string be released during the revolution, A will fly off at a tangent, as indicated by the straight lines.

235. Heat is usually measured by the expansion of a liquid or gas, it having been found that equal additions of molecular motion produce (α) in the case of gases equal alterations in bulk irrespective of the nature of the gas (N. 230); (β) in the case of liquids nearly equal alterations in bulk in the same liquid, although different alterations in different liquids. (*Thermometry:* θέρμη, heat; μετρέω, to measure.)

236. *Temperature* (*temperatura, tempus,* from τέμνω, to cut; literally a portion cut, or measured off, hence *time*) is a term employed to designate the relative amounts of *sensible* heat associated with two or more substances. It is measured by thermometers and pyrometers.

237. The thermometers in most general use are the Centigrade and the Fahrenheit; in the former the stem is divided into 100 equal divisions (called *degrees*) between the freezing and the boiling point of water, and in the latter into 180 equal divisions. The zero of the Centigrade thermometer is 0°, and of the Fahrenheit 32°. Hence—

$$N^\circ\ C. \div 5 \times 9 + 32 = \text{Fahrenheit degrees.}$$
$$N^\circ\ F. - 32 \div 9 \times 5 = \text{Centigrade degrees.}$$

238. *Evaporation* (*evaporo,* to disperse in vapour) is the conversion of a liquid into gas at its exposed surface. The molecules at the surface, unlike those in the mass of the liquid, are influenced and restrained by the proximity of other molecules in *one direction*

only; hence, in the language of the above hypothesis (N. 234), they more readily assume the rectilinear motion appertaining to the molecules of a gas.

239. *Ebullition* or boiling (*ebullio*, to boil, or bubble up) is the conversion of a liquid into gas by the assumption of rectilinear motion by the molecules in the interior of the liquid mass. The liquid continues to receive molecular motion until the cohesion of its molecules (*plus* or *minus* any of the extraneous actions mentioned below) is overcome, and the molecules thus freed from restraint part company with the liquid in the form of bubbles of gas.

240. The temperature at which this takes place, subject to the conditions which at that time prevail, is called the *boiling-point* of the liquid under those conditions.

241. The boiling-point of a liquid is influenced by the following causes: (*a*) external pressure, which by limiting the motion of the molecules, and thus assisting cohesion, raises the boiling-point; (β) the substance of the containing vessel, between which and the liquid molecules a certain attraction, differing for different substances, exists, which consequently assists cohesion, and raises the boiling-point; (γ) dissolved substances, which in the case of dissolved solids tend to raise the boiling-point, and in the case of dissolved air to lower it.

242. Thus, water boils: (α) at a lower temperature on the summit of a mountain than at its base; (β) at a higher temperature in a glass than in a metal vessel; (γ) at a higher temperature when it contains salt in solution, as in sea-water, than when it is free from dissolved solids, as in rain-water; and at a far

higher temperature when it is freed from dissolved air than when it contains air in solution.

243. *Evaporation in the spheroidal condition* is the surface evaporation of a liquid spheroid floating upon a layer of its own gas, which separates it from direct contact with a surface possessing a higher (usually, but not necessarily, a much higher) temperature.

244. The attractive force existing between the molecules of matter, like all other attractive forces, decreases in intensity as the distance between the attracting molecules increases, and *vice versâ.* Liquids become solids (*Solidification*) when they lose so much of their molecular motion that the molecules approach sufficiently near to each other to produce the effect of rigidity, in place of the former molecular mobility.

245. When the resulting solid assumes a definite geometrical form (*Crystallisation*), the attractive force of its molecules probably varies in intensity in different directions: thus, supposing the molecules to be spherical, the attractive force would be greater or less in the direction of one diameter than in the direction of a diameter cutting it at right angles; or supposing the molecules to be ellipsoidal, the attractive force would be greater or less in the direc-

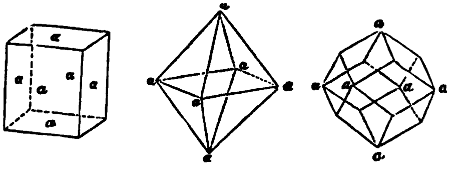


Fig. 32.

tion of the major axis than in the direction of the minor axis. Fig. 32 shows several crystalline forms—viz. the cube, octohedron, and dodecahedron.

246. When the resulting solid does not assume a crystalline structure or form, the attractive force of the molecules probably does not vary in different directions, or the varying intensity may be equalised by extraneous causes. (*Amorphous solidification.*)

247. Water and a few other substances do not continue to contract (N. 221) as long as they continue to be cooled. Water contracts until it is cooled down to 4° C. (39·2° F.), after which it expands on further cooling. Thus water at 3° C. has the same density as water at 5° C.; and ice at 0° C. is lighter than water at 4° C., in the ratio of 0·91800 to 1·00000.

248. At 4° C. water therefore possesses its *maximum density*; that is to say, any given volume contains a larger number of molecules at that temperature than at any other temperature.

249. When molecular motion is communicated to a substance, it is obvious that before it can expand that substance it must overcome the mutual attraction of its molecules at the particular distance at which they then exist, for expansion is the act of increasing the distance between individual molecules (N. 220). In thus separating the molecules there is, consequently, a certain amount of work to be done (*the internal work of a mass of matter*), just as the separation of two masses—for instance, the raising of a weight to a height above the surface of the earth—involves the expenditure of an amount of work equal to the force of gravity which has been overcome, and

in both cases alike, heat is consumed in the performance of the work done.

250. As when a weight is raised above the earth's surface it possesses potential energy (N. 104) competent when converted into kinetic energy (N. 105) to cause it to fall through the space which separates it from the earth, and to generate the heat consumed in raising it when its kinetic energy is arrested; so, likewise, the molecules of a substance expanded by heat possess potential energy (*molecular potential energy*), competent to cause them to re-cross the space through which they have been separated by the added molecular motion, and to generate the heat consumed in separating them when the kinetic energy thus induced is arrested.

251. Since all matter possesses a certain amount of molecular motion, and no two molecules are in contact, it follows that all molecules possess a certain amount of potential energy, and that the acts of heating and cooling (addition and subtraction of molecular motion), may be expressed respectively as the increasing and the lessening of molecular potential energy, considered in regard to its amount at the time of such addition or subtraction.

252. From the above statements it follows that when motion is communicated to molecules, it performs two functions; for a portion of it is converted into work, which confers potential energy upon the molecules by separating them to a greater distance (*expansion*, N. 220), while another portion increases the temperature of the substance (N. 236), by conferring upon the molecules a larger quantity of the motion which constitutes heat, and hence increasing

their velocity. Thus a portion of the added molecular motion disappears as heat, and this is still known as *Latent Heat.* (*Lateo,* to lie hid, because it was imagined by those who adopted the material theory of heat (N. 206) that the heat thus designated was somehow hidden in the substance, as in a cave, and that it only came out under certain conditions, and this idea was one of the most notable of the many *idola specus* possessed by the Materialists.)

253. The quantity of heat which is thus expended in internal work (N. 249) when a solid passes into the liquid, or a liquid into the gaseous condition, can be readily determined. Thus if a pound of boiling water (212° F.), be mixed with a pound of ice-cold water (32° F.), the temperature of the resulting two pounds of water is found to be 122° F., that is, the mean of the two : $\frac{212^\circ + 32^\circ}{2}$F. = 122° F. But if a pound of ice (32° F.) be mixed with a pound of boiling water, the temperature of the resulting two pounds of water is found to be only 51° F. Now it is obvious that the difference in the total heat of the two mixtures is that required to raise two pounds of water 122° – 51° F. = 71° F., or one pound through 142° F. In other words, in the act of liquefying a pound of ice at 32° F., an amount of heat is consumed as internal work, which is competent to raise one pound of water through 142° F., that is to say, 142 units of heat (N. 210), which represents as mechanical work one pound raised to a height of 772 × 142 feet = 109,624 feet (or more than 20 miles), above the surface of the earth (N. 211).

254. The actual amount of molecular motion possessed by different substances (*Specific Heat*) varies

considerably, for not only do the molecules in a given space vary in number, but also in weight, and in their attraction for each other; hence also the amount of heat consumed in internal work varies because it depends upon the relative attraction of the molecules.

255. The amount of molecular motion necessary to raise any substance through a known number of thermometric degrees (N. 237) compared with that necessary to raise the same weight of water through the same number of degrees, is called the *specific heat* of that substance. Thus to raise 1 lb. of water 1° F. in temperature requires thirty-three times the amount of heat necessary to raise 1 lb. of mercury 1° F. in temperature; hence the specific heat of water being represented by 1·00, that of the mercury will be ·033.

256. *Conduction of Heat* is the transference of molecular motion from molecules possessing a certain amount of it, to molecules possessing less of it, by direct communication of motion. Those molecules which are apt to receive and transmit the motion are called *conductors of heat*, while those which are unfitted for the reception and transmission of the motion (whether from their slight mobility, or from an inaptitude to accommodate themselves to that form of motion) are called *non-conductors of heat.*

257. *Convection* (from *conveho*, to carry up) is an action induced by external means—the force of gravity,—in virtue of which a congeries of molecules of liquid or gas, possessing a greater amount of molecular motion than a surrounding congeries or system of congeries, rises *en masse.* This is due to the fact that the motion of heat, by increasing the distance

between the molecules of matter (N. 220), causes a given number thereof to occupy a larger space when they possess a certain amount of that motion than when they possess relatively less, whence ensues a difference of density, and a consequent difference of action on the part of gravity, for in equal bulks there are no longer equal weights of matter, and one mass is now attracted by the earth more powerfully than the other.

258. If a mass of matter possessing a greater amount of molecular motion than the matter around it (a heated ball of metal for example), be suspended in a place devoid of all directly recognisable matter (N. 154), it is found that it rapidly loses its motion, until it assumes the temperature of proximate surrounding bodies; and inasmuch as that motion proceeds in straight lines in every direction like the radii of a circle, the action is known as *Radiation*, and the motion thus transmitted as *Radiant Heat*. (*Radius*, a rod, the spoke of a wheel, related to ῥάβδος. *Radio*, to emit beams, to shine, is not unfrequently used by the ancients; thus Lucretius, "*rubent radiati lumina solis.*")

259. It is impossible *à priori* that in this case there can be direct transmission of heat by conduction (N. 256), or by convection (N. 257); the motion is not communicated to visible and readily recognisable matter, but to that infinitely subtle matter called the *Ether* or *interstellar medium* (Αἰθὴρ of the ancients) (N. 170); and it is believed to travel in progressive waves, that is such waves as are produced when a long cord fixed at one end is rapidly jerked up and down.

260. There is no transference of matter, only of

motion, and each particle of the ether actuated by the motion moves at right angles to the direction of transmission (N. 175).

261. Radiant heat is closely related to light; indeed we have every reason for believing that the motion which constitutes heat is only a slower form of the motion which constitutes light; in a word, that the difference is one of degree rather than of form. Thus, if we heat a mass of metal it gradually assimilates molecular motion until at a certain point (*red heat*), it emits light, and the more motion it receives the more intense does the light become, until at length it emits white light (*white heat*).

262. Again, when light is decomposed by a prism, that is when the various ether-waves which (in virtue of difference of oscillation) constitute differently coloured lights, are separated, so that waves of one definite velocity appear in one definite place, it is found that beyond the slowest waves of light there are waves of radiant heat of extreme power.

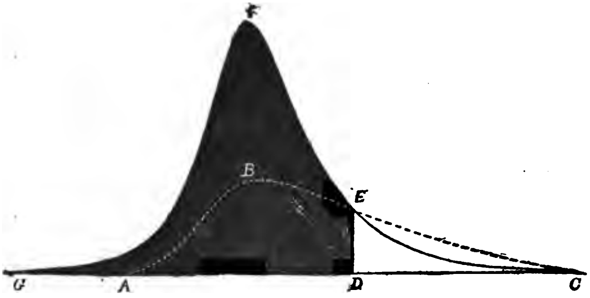


Fig. 33.

If D C represents the length of the visible spectrum (N. 196), and D E the termination of the red end, the curve A B E C represents the distribution of heat in the solar spectrum, as determined by Müller. The relative intensities of the heat-rays are represented by the different heights of the curve above the horizontal line G C. Tyndall has, however, constructed the curve G F E C to represent the heat spectrum of the electric light; and he thus determined that the obscure radiation is nearly eight times the visible, while in Müller's spectrum it is not more than twice as great. This is probably due, according to Tyndall, to the fact that much of the heat of the sun is absorbed by aqueous vapour before the sunbeam reaches us.

263. The intensity of radiant heat diminishes as the square of the distance of the radiant body increases. Thus, double the distance, and the heat is reduced to one-fourth; treble the distance, and the heat is reduced to one-ninth, and so on.

264. Prevost's *Theory of Exchanges* asserts that an interchange of heat is perpetually taking place between all substances. If a body radiates more heat than it receives, the temperature falls; while, if it receives more heat from other bodies than it radiates, the temperature rises. When a number of bodies in proximity possess the same amount of sensible heat, they radiate as much heat as they absorb, and no change of temperature is apparent. The rate of radiation depends upon the substance and temperature of the radiating substance.—(*Theory*, from θεωρία a contemplation, θεωρέω, to view, an explanation well supported by facts, but not absolute, and to be received provisionally for the better grouping together of facts, and the better classification of ideas.)

265. Radiant heat is capable of *reflection* (*reflecto*, to turn back), and it obeys the same law as light. Reflection may be defined as the turning back of the ether-waves by molecules which cannot assimilate the motion thus conveyed, as when a cord is fixed to a rigid body and caused to undulate, the wave which travels along it stops when it reaches the fixed end, and then returns, because the rigid body is incompetent to assimilate the motion which the molecules of the cord convey.

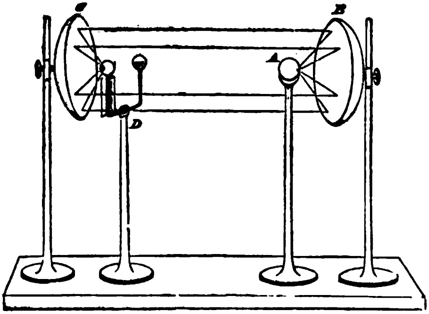


Fig. 34.

In Fig. 34 B C represent two reflectors: if a hot body A be placed in the focus of B, an air thermometer D in the focus of C is easily affected through a space of many feet.

266. Radiant heat is capable of being *refracted* (*frango*, to break up, akin to ῥάσσω), that is the motion of the ether-waves may be turned by their passage through certain media, so as to proceed in a different direction and in an extended form.

267. Dew (δεύω, to moisten) is moisture deposited

from the air on account of the cold produced by terrestrial radiation. When the sun goes down, the earth commences to pour out into space the heat which it received during the day, consequently the layer of air resting on the earth becomes chilled, and a portion of its aqueous vapour is deposited. Clouds prevent free radiation into space, hence dew is deposited most copiously during clear nights.

268. The *dew-point* is the degree of temperature (N. 235, 236) at which dew begins to be deposited. It may be determined by means of an instrument called an *Hygrometer* (ὑγρὸς, moist; μετρέω, to measure).

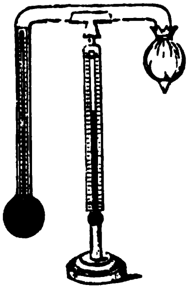


Fig. 35.

Fig. 35 shows Daniell's Hygrometer, which consists of two bulbs united by a tube bent twice at right angles. The left-hand bulb of black glass contains a small quantity of water, and encloses a thermometer. If ether be poured on the other bulb, its evaporation will, by producing cold, cause the aqueous vapour in the bulb to condense, further evaporation will take place from the water in the other bulb, and its temperature will thus be lowered until dew is deposited upon the outside of the black bulb. The temperature of the inside thermometer is now noted, and compared with the temperature of the air.

269. The *absorption* (*absorbeo*, to swallow up, or devour) of heat is the reception of the motion from the ether by molecules of matter; it is thus a reverse action to reflection, for absorption presupposes that the molecules of the absorbing body readily assimilate the motion. Such molecules may be represented by small wooden balls suspended in the path of a cord, which latter, when caused to undulate, communicates its motion to the balls.

270. Good radiators of heat are also good absorbers; in other words, those particles which readily transmit motion to the ether also readily receive it from the ether; they are, in fact, prone to accommodate themselves to that special form of motion.

271. Of the total radiation of the sun only $\frac{1}{2300000000}$ is received by the earth. With the exception of the energy of tides (that is the energy derived from the ebb and flow of the tides, which results from the attraction of the moon, and tends to diminish the energy of the earth's revolution) the sun is the source of all our available energy, the energy of fuel and food, and of water, and air in motion. The most dominant attractive forces against which this energy is exerted are (α) *Gravity*, the attraction existing between masses of matter (N. 62); (β) *Chemical affinity*, the attraction existing between dissimilar molecules of matter; and (γ) *Cohesion*, the attraction existing between similar

molecules of matter (N. 13). The energy expended in the internal work of a mass of matter (N. 249), enormous as it is, is obviously unavailable to mankind.

272. The total amount of heat emitted by the sun would raise 700,000,000,000 of cubic miles of water at 0° C to the boiling point, *per hour;* and this waste of heat has continued for ages.

273. Several theories have been proposed in order to account for the production and maintenance of this enormous amount of heat. The *meteoric theory* proposes to ascribe it to the impact of meteoric bodies against the surface of the sun. The force of gravity at the surface of the sun is twenty-seven times greater than at the earth's surface; thus a pound weight would weigh nearly two stone if removed to the sun, and a body 436 feet above the sun would fall to its surface in one second. The velocity of a mass of matter near the surface of the sun would be far greater than the velocity of the earth in its orbit, and a large amount of heat would be generated by its impact with the sun. It has been calculated that a terrestrial pound of matter falling into the sun would generate an amount of heat equal to that produced by the union of 2800 lbs. of carbon with oxygen gas. Thus if we suppose that the sun is perpetually attracting to its surface meteoric bodies which are floating about in space, we have a fertile source of heat. On the other hand, Helmholtz proposes to account for solar heat on the assumption that the sun (the density of which is only one-quarter that of the earth) is contracting, and thus converting kinetic energy into heat. It has been estimated that the heat developed by the contraction of the sun equal to

one ten-thousandth of its diameter would be sufficient to supply the expenditure of more than two thousand years.

Experimental Illustration of Heat.

No science lends itself with greater facility to the purposes of experimental illustration than heat. The determination of the mechanical equivalent of heat should be illustrated as fully as possible:—(α) by a demonstration of the laws of falling bodies by Atwood's machine; (β) by a model of Joule's apparatus (Fig. 28), which may easily be constructed with tin vanes worked in water by a weight of a few pounds, caused to fall from the ceiling of the lecture-room, and thus to give rotation to the paddle; (γ) by showing the various units; (δ) by shaking water and mercury violently in bottles thickly enveloped in flannel to prevent conduction, and showing the rise of temperature. The principles of potential and kinetic energy can be readily illustrated by means of a weight (a sphere of lead weighing about a pound, and furnished with a hook, is useful for the purpose) passed over a pulley at the highest point of the lecture-room. The transformation of kinetic energy into heat can be shown by various means, which will suggest themselves to the student—such as hammering a bar of lead or tin, boring a hole with a gimlet, rubbing two metal sufaces together. The production of heat by chemical means admits of ready demonstration:—the union of sulphuric acid with water (by the heat of which a test tube of alcohol immersed in the mixture may be readily caused to boil, and the alcohol vapour may be lighted at the mouth of the tube), or the union of phosphorus with iodine, furnish examples. The consumption of heat in the performance of mechanical work (as in the steam-engine) is so obvious that it scarcely requires proof. The expansion of solids, liquids, and gases may be easily shown by various means. A large alcohol thermometer, and several mercury thermometers, will be found useful; also a good differential air thermometer, preferably that which was devised by Dr. Matthiessen. A thermo-electric pile is useful for many experiments; it should be connected with a large but sensitive galvanometer, the upper needle of which may be prolonged by means of thin aluminium wire furnished with light terminations of coloured paper, in order that its movements may be readily visible at a distance. A number of small wooden balls, about 1½ inch diameter, and of different colours, will be found useful for the better realisation of certain atomic actions; such, for instance, as the hypothesis of the rectilinear motions of the atoms of gases through space. To illustrate this, one of the balls may be attached to a helical spring of brass wire, and may be whirled about the remote end of the spring as a centre: then it will be observed that as the velocity increases the distance of the ball from the centre about which it rotates will also increase; and if at any point of its rotation it be released, it will fly off at a tangent to its former path. Illustrations of evaporation, ebullition, and evaporation in the spheroidal condition, present no difficulties. The latter may be well shown by the flotation of a small ball of white-hot silver on the surface of water, or by the more usual flotation of a liquid spheroid upon a layer of its own gas in a red-hot platinum dish. Experiments are much wanting for the ready and apt illustration of Latent Heat and Specific Heat. Conduction and convection may be well illustrated. The experiment of boiling water over a piece of ice is easy of accomplishment, and very conclusive as to the slight conductibility of liquids. Some form of electric or other lamp is necessary for the illustration of Radiant Heat; and for complete experiments, a train of prisms and lenses of the purest and most transparent rock-salt. The so-called *parabolic* mirrors, which are sold in this country for showing the reflection of heat, are often segments of a sphere; but good parabolic mirrors may be obtained in Paris at a not unreasonable rate.

MAGNETISM.

274. There exists in nature an ore of iron called "Magnetic oxide of iron" ($Fe_3 O_4$), containing in 100 parts, Iron 72·41, and Oxygen gas 27·59. This ore possesses the peculiar property of attracting iron.

275. Magnetic iron ore was known to the ancients, and was termed *μάγνης* by the Greeks, because it was first found in Magnesia. Hence our term *Magnetism*, to denote the science which treats of the modes and properties of the attractive force.

276. The force is not confined to the mineral, for if a steel bar be rubbed by a piece of magnetic iron ore, it acquires the attractive property of the ore. (*Magnetisation.*)

277. The ore is termed a *Natural Magnet;* a steel bar to which the force has been apparently communicated, an *Artificial Magnet.*

278. If we examine a bar of magnetised steel, we at once notice that the force is not evenly distributed. If we dip it in iron filings, tufts of the filings cling to the ends of the bar, while none are seen at the centre of the bar. If the bar at either end will sustain, say, 10 grammes of iron, at a little distance from the end it will sustain only 5; still nearer the centre only 1; and at the centre itself—viz. exactly midway between the two ends—it will not sustain any weight at all.

279. The ends of the bar, at which the force appears to be concentrated, are called the *Poles* of the magnet.

The centre of the bar midway between the poles is termed the *Equator*, or *neutral line* of the magnet. The terms are obviously borrowed from those which we apply to the earth. (*Pole*, from πόλος, an axis or pivot, πολέω, to turn ; the points about which the earth revolves. *Equator*, that which divides into equal parts ; *æquus*, equal.)

280. A small light magnet, balanced and freely suspended by its centre, is called a *Magnetic Needle* (Fig. 36). It assumes a position approximately parallel to a line joining the north and south geographical poles. In other words, one end of the needle approximately points to the north, and if it be turned round, so as to point to the south, or east, or west, a certain resistance is experienced, and when the needle is released it turns again to the north.

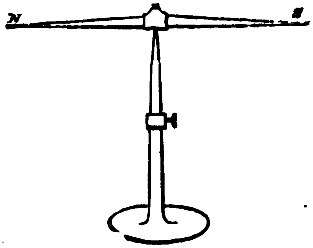


Fig. 36.

281. That end of a freely suspended magnetic needle which turns to the north is called by us the *North Pole*, and sometimes the *North-seeking Pole*, of the magnet: by the French, the *South*, or *Austral Pole*. Hereafter we shall speak of the north-seeking pole as the *North Pole*, and the south-seeking pole as the *South Pole*, according to our English usage.

282. If the north pole of a magnet be placed near the north pole of a suspended magnet, the latter is repelled; while if the north pole is placed near the south pole of the suspended magnet, the latter is attracted. Hence, similar poles repel, and contrary poles attract one another. Remembering this law, we have a ready means of determining the poles of a magnet.

283. Magnetic attraction and repulsion varies inversely as the square of the distance between the magnet and the body attracted or repelled. Thus, if the distance be doubled, the attraction is diminished to one-fourth; if the distance be trebled, the attraction is one-ninth, and so on (comp. Notes 180, 263).

284. Magnetic poles always occur in pairs. If a magnet be broken into many pieces, each fragment is found to have its north and south pole. Indeed, it is believed that every atom of a magnet is a perfect magnet. (*Atom*, from ἀ, not, and τέμνω, to cut; literally, that which cannot be divided. The ultimate particles of matter are called atoms; they are believed to be invisible by reason of their smallness, indivisible, infinitely hard, and spherical.)

285. Let us, for the better realisation of magnetic phenomena, assume that all matter is pervaded by an extremely subtle fluid, incapable of recognition by our senses, and possessing no active properties. And let us assume that this *neutral fluid* is composed of *north magnetic fluid*—viz. that fluid which resides in the north pole of a magnet, and of *south magnetic fluid*. A bar of steel may be supposed to be pervaded by this neutral fluid, and the act of magnetisation (N. 276) to be the separation of the neutral fluid into its

active component fluids. This is known as the *Hypothesis of two Magnetic fluids.* (*Hypothesis,* from ὑπό, under, τίθημι, to place; ὑπόθεσις, the foundation of an argument; a something assumed to explain that which is not understood. *Suppositio* is the exact Latin equivalent. Hypotheses, although always to be received with caution, are frequently of great service to science; for if they are based upon accurate experimental facts, they help the intellect to associate together similar classes of facts; and they often suggest fresh phases of experiment.)

286. The magnetisation of a steel bar may be viewed as the magnetisation of every atom it contains; the spherical atoms which contained neutral magnetic fluid having now a north and south hemisphere and an equator. The north poles are all turned in one direction; the south poles in the opposite direction; in fact, the bar is *polarised.*

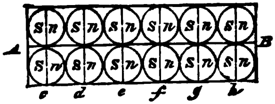


Fig. 37.

287. The term *polarity* is frequently employed in Natural Philosophy to signify the existence of equal and opposite qualities in opposite portions of a particle or mass, or equal and opposite actions in a line of force.

288. The atoms of *soft iron* (*i.e.* ordinary wrought-iron, which is soft compared with hardened steel) do not suffer permanent polarisation by a magnet. A soft iron bar acts like a magnet so long as it is in contact with a magnet (N. 291), but it retains no

magnetic force after separation from the magnet, or if it be rubbed by it. On the other hand, a steel bar allows its atoms to be permanently polarised, and remains magnetic.

289. The magnetised steel bar is termed a *permanent magnet*, the iron bar a *temporary magnet.* Steel is said to possess *coercive force* (*coerceo*, to restrain), a kind of force which tends to prevent the opposite magnetic fluids from rushing together across the equator of the magnet, and combining to form the neutral fluid.

290. That the opposite fluids do neutralise each other may be proved by placing the north pole of one magnet in contact with the south pole of a magnet of equal strength; all attractive force now disappears, and we have a magnetically-inert compound steel bar; separate the bars, and we have two magnets again.

291. Let us imagine a horizontal bar of soft iron, *AB*; if now we approximate one of the poles (say the north) of a permanent magnet to the end *A*, the iron bar is found to be a magnet, the end *A* being a south pole, and the remote end *B* a north pole. This action is called *Induction.* It is exerted not alone through an intervening space of air; the magnet may be separated from the soft iron by a plate of glass, wood, metal, etc., without detriment; or the soft iron may be in contact with the magnet.

292. Induction may be defined as the temporary decomposition of the neutral fluid of soft iron into its constituent north and south fluids. The condition vanishes as soon as the magnet is withdrawn, because soft iron possesses no coercive force (N. 289). The

neutral fluid is decomposed because the separated north or south fluid of the magnet attracts one of its constituent fluids, and repels the other (N. 282).

293. The neutral fluid of a steel bar may be decomposed, either by powerful induction, or by stroking the bar in one direction with one pole of another magnet. In the latter instance the end of the steel bar which is last touched by the magnet possesses an opposite pole to that of the magnet used. (Compare N. 276.)

294. Iron is not the only substance which is attracted by a magnet. Nickel, cobalt, manganese, chromium, platinum, oxygen gas, and many other substances, suffer attraction.

295. Heat powerfully influences magnetism. A magnet if heated to redness loses all its magnetism, and a red-hot ball of iron is not attracted by a magnet.

296. Every magnetic substance has its limit of temperature: thus, cobalt does not cease to be attracted even at a white heat; iron ceases to be attracted at a bright red heat; chromium just below a red heat; nickel at 350° F.; and manganese is not attracted on a warm summer's day.

297. Hence it is probable that certain substances, which do not appear under ordinary circumstances to be attracted by a magnet, would be attracted if their temperature was reduced to a sufficiently low degree.

298. A magnetic needle tends to set itself in a line with the poles of the earth, and if moved from this position returns to it (N. 280), as if it were in

the presence of another magnet. This is due to the magnetism of the earth.

299. In fact, the earth is a huge magnet, the poles and equator of which do not coincide with the geographical poles and equator.

300. We now understand why the pole of a suspended magnet which turns to the geographical north is called the *South Pole* by the French (N. 281). For opposite poles attract (N. 282); hence the pole of a suspended magnet which is attracted by the north magnetic pole of the earth must be a south pole.

301. The *magnetic meridian* of a place is a vertical plane which passes through the two poles of a horizontally suspended magnetic needle at this place, and which, being continued in both directions, will of course pass through the magnetic poles of the earth.

302. The magnetic meridian of a place will obviously not coincide with its geographical meridian, and the angle enclosed by the two meridians is called the magnetic *deviation*, *variation*, or *declination* at this place. (*Declino*, to deviate from.)

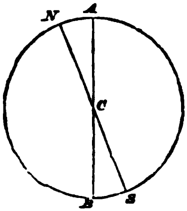


Fig. 38.

Thus if A B represent the geographical meridian, N S represents the direction assumed by a horizontally suspended magnetic needle in London; and the included angle N C A is the deviation.

303. The deviation of the magnet from the true north is believed to have been known to the Chinese as early as the commencement of the eleventh century; it is also mentioned in a MS. now in the library of the University of Leyden, written in 1269, and it was fully recognised by Sebastian Cabot, Christopher Columbus, and other navigators.

304. The variation does not always remain the same. In 1580 (the first year in which accurate observations were made), the north end of the needle deviated 11° 15′ to the east of the true north in London; in 1622 the deviation was 6° *east* of the north, and in 1660 the magnetic north pole coincided with the geographical north pole. In 1692 it had passed to 6° *west* of the north; in 1765 it was 20° west, and in 1818 it attained its maximum westerly deviation—24° 41′. It is now returning to the north; in 1850 the westerly declination was 22° 30′, and in October 1871 the deviation, observed at the Kew Observatory, was 20° 18′ 7″. This is the *secular variation* of the magnetic needle. (*Seculum*, an age.)

305. A delicately suspended magnet may be observed to undergo annual, daily, and even horary variations. Between 7 and 8 A.M. the north pole of the needle begins to move to the west, and this continues till 1 P.M.; the needle is then stationary for a short time, then it commences to return, and reaches the point from which it started at about 10 P M. During the night a smaller extent of variation takes place; the needle moves towards the west till 3 A.M., and

slowly returns to its original starting place, which it reaches between 7 and 8 A.M.

306. Lines connecting those places on the earth's surface at which the magnetic variation is the same, are called *isogonal lines* (ισος, equal ; γωνια, an angle).

307. If a steel needle be accurately balanced about a horizontal centre, and be then magnetised, it will no longer be in equilibrium. In London the north end of the needle will dip down, forming an angle of more than 60° with a horizontal plane.

308. The angle which a magnetic needle capable of vertical movement (*dipping needle*) makes with a horizontal plane is called the angle of *inclination* or *dip*. The vertical plane in which the needle moves must coincide with the magnetic meridian of the place.

309. The dip varies in different parts of the world. If we convey a dipping needle north of London the dip increases ; if, on the other hand, we go south of London, the dip diminishes. At the magnetic equator there is no dip, the needle is perfectly horizontal ; and south of the equator the south pole of the magnet begins to dip, and the dip increases as we go farther south. Thus the dip at Peru is 0°, at Lima 10° 30′, at the Cape of Good Hope 34°, and at Hudson's Bay between 89° and 90°.

310. The *magnetic poles* of the earth are those points on the earth's surface at which a dipping needle assumes a vertical position. The North Magnetic Pole was discovered by Sir James Ross in 1830. It is situated in long. 96° 43′ W., lat. 70° N. The South Magnetic Pole has not yet been discovered.

311. Lines connecting those places on the earth's surface at which the magnetic inclination is the same are called *isoclinic lines* (*ἴσος*, equal; *κλίνω*, to incline).

312. The *Magnetic Equator* of the earth is a line connecting all those places on the earth's surface at which there is no dip. The magnetic equator is hence sometimes called the *aclinic line* (*ἀ*, not; *κλίνω*, to incline). It is an irregular closed circular line cutting the terrestrial equator at four points.

313. The dip of a magnetic needle is subject to both secular and periodical changes. Thus in 1576 it was 71° 51′ in London; a hundred years later it was 73° 30′, and in 1723 it reached a maximum of 74° 42′. In 1800 it had decreased to 70° 35′, and in October 1871 the dip registered at the Kew Observatory was 67° 56′ 3″. The dip also undergoes slight annual and daily changes.

314. If a horizontally suspended magnetic needle be moved from its position of rest, it returns to it, passes it, and oscillates backwards and forwards across the final position of rest in the magnetic meridian of the place; in fact, it becomes a horizontal pendulum oscillating under the influence of the earth's magnetism. It has been proved that the *intensity* of the earth's magnetism at any two places is proportional to the square of the number of oscillations made by the same magnetic needle at these places.

315. Various determinations of the intensity of the earth's magnetism prove that the force increases as we pass from the equator to the poles, as in an ordinary bar magnet (N. 278). Thus, if the intensity at Peru be taken as unity, the intensity in London

will be represented by 1·369, and at Baffin's Bay by 1·707.

316. Lines connecting those places on the earth's surface at which the magnetic intensity is the same are called *isodynamic lines* (ἴσος, equal; δύναμις, force).

317. All matter is affected by a powerful magnet; but while many substances (iron, nickel, manganese, oxygen gas, etc.) are attracted, other substances (bismuth, copper, hydrogen, etc.) are repelled by *both* poles of the magnet.

318. If a small bar of iron or other attracted substance be suspended between the poles of a magnet, the bar will set itself *axially*, that is with its length in a line joining the two poles. If, on the other hand, a bar of bismuth or other repelled substance be suspended in a like position, it will set itself *equatorially*, that is, at right angles to a line joining the poles of the magnet, because, as it is repelled by both poles, it will endeavour to keep as far away from them as possible. Such bodies are called *diamagnetic*.

319. If a small glass globe, containing a solution of a salt of iron, be suspended in a stronger solution of the same salt and acted upon by a powerful magnet, the globe containing the weaker solution will be repelled; although a salt of iron is highly magnetic. It appears to be repelled for the same reason that an ascending balloon appears to be repelled by the earth. In the latter instance, gravity attracts the air surrounding the balloon more forcibly than it attracts the balloon, hence the effect of repulsion. In the case of the globe containing the solution of iron-salt, the magnet attracts the surrounding stronger solution more readily than it attracts the weak solution in the

globe, hence the latter is repelled. Any magnetic substance suspended in a liquid more magnetic (*i.e.* more strongly attracted) than itself will be repelled like a diamagnetic substance; and any diamagnetic substance suspended in a liquid more diamagnetic (*i.e.* more strongly repelled) than itself, will be attracted like a magnetic substance.

320. From this experiment it has been inferred that magnetism and diamagnetism are the same force, and that a substance is attracted by a magnet when the ether (N. 170) is less strongly attracted than itself, and repelled when the ether is more strongly attracted than itself.

Experimental Illustration of Magnetism.

Magnetism may be easily illustrated by means of a small collection of very simple apparatus:—Two bar magnets of good steel, about 12 inches long by 1½ inch broad, and ¼ inch thick; a horse-shoe magnet, about 6 inches long; several bars of soft iron; some filings, small rings, and small cylinders of soft iron; and three or four well-balanced magnetic needles, about 6 inches long, are almost all the requisites. A piece of magnetic-oxide of iron, some steel knitting-needles about a foot long, and a magnetic needle capable of vertical movement, for showing dip, should be added. A powerful electro-magnet is necessary for diamagnetic experiments.

STATIC ELECTRICITY.

321. The ancients were acquainted with the fact that amber when rubbed acquires the property of attracting light bodies. This observation is said to have been first made by Thales of Miletus (B.C. 600); and in allusion to it, more than twenty centuries after his time, the peculiar attractive force was called *Electricity*, from ἤλεκτρον, amber.

322. In 1600 Dr. Gilbert of Colchester, physician to Queen Elizabeth, published a work entitled *De Magnete*, in which he extended the solitary observation of Thales, by showing that the attractive force may be developed by the friction of many other substances, such as glass, sealing-wax, sulphur, precious stones, etc. The birthplace of both the sciences of electricity and of magnetism is Gilbert's treatise *De Magnete.*

323. Kinetic energy (N. 105) is readily transformed into electricity. Friction is a most fertile source of electricity. (Compare N. 215.) Heat may be generated by the friction either of bodies which are identical in composition, structure, state of aggregation, temperature, etc., or which are different in these respects. Electricity, on the other hand, is only generated when the bodies submitted to friction differ in some quality or qualities, such as composition, structure, temperature, etc.

324. Electricity may also be produced by compression and cleavage; by heat, evaporation, and chemical action.

325. We notice at once that the causes which produce electricity are in many instances precisely identical with those which produce heat (N. 214, 215). We shall find indeed that electricity and heat are very closely connected; and although we know far less of the actual nature of the former than of the latter, and are hence compelled to make use of working hypotheses (comp. N. 286), we may reasonably assume that electricity, like heat, is a peculiar motion of the molecules of bodies.

326. The attractive force, when once evoked, is found to be easily transmitted by certain bodies, notably the metals; while it will not pass along other bodies, notably resinous and vitreous substances. (Comp. N. 256.) Those bodies which allow electricity to pass along them are called *conductors of electricity*, those which offer resistance to its passage, and more or less completely intercept it, *non-conductors.* (See also N. 342.) *Conductivity* and *Resistance* are antithetical terms.

327. Good conductors of heat are also good conductors of electricity, and *vice versâ.* There is a remarkable relationship between the conductivities of similar substances for heat and for electricity. Thus, if the conductivity of silver be taken as 100 in both instances, the conductivity of copper is 74 for heat, and 73 for electricity; of iron 12 for the former, 13 for the latter; of bismuth 2 for the former, and 2 for the latter.

328. A body is said to be *insulated* when it is separated from contiguous conductors by a non-conducting substance. Hence non-conductors are sometimes called *insulators* (*insula*, an island).

329. If a light suspended body (such as a pith ball) be attracted by the electricity of a rubbed glass rod, it is seen to approach the rod, touch it, and then be repelled. If we suspend a rubbed glass rod, and approach to it a second rubbed glass rod, repulsion is also apparent; but if we place near the suspended rod a rod of rubbed sealing-wax, attraction takes place. Hence the electricity produced by rubbing glass is different from the electricity produced by rubbing sealing-wax.

330. The electricity produced by rubbing glass with silk is called *Positive electricity,* and is represented by the sign +. The electricity produced by rubbing sealing-wax with flannel is called *Negative electricity,* and is represented by the sign –.

331. From N. 329 we learn that similar electricities repel, and contrary electricities attract one another. Thus + repels +, and attracts –; and – repels –, and attracts + electricity. (Comp. the law relating to the mutual action of magnetic poles, N. 282.)

332. Electrical attraction and repulsion follows the same law as that which regulates magnetic attraction and repulsion (N. 283); that is to say, it varies inversely as the square of the distance between the electrified body, and the body attracted or repelled.

333. *Electroscopes* (σκοπέω, to see) are instruments which are used for indicating the presence of free electricity, and for determining whether such electricity be positive or negative. Thus the suspended pith ball before mentioned (N. 329) is a very useful electroscope, so also is a delicately suspended rod of glass, or caoutchouc. The *gold-leaf electroscope* con-

sists of two leaves of gold-leaf which hang very near to each other, and are insulated. When electricity is communicated to them they repel each other, in accordance with the known law (N. 331). *Electrometers* (*μετρέω*, to measure) are measures of electrical force. One of the most useful of these is Coulomb's *torsion electrometer*, in which the force is measured by the degree of torsion (*torqueo*, to twist) communicated to a thread which carries the attracted or repelled body (N. 23).

334. In order to account for the existence of the different modifications of the same electrical force (N. 329), a *two-fluid hypothesis*, analogous to the hypothesis of two magnetic fluids (N. 285), has been proposed. This we may accept provisionally for the better conception of electrical phenomena. Let us then assume that all matter is pervaded by an extremely subtle fluid, which like the neutral magnetic fluid is incapable of recognition by our senses and devoid of active properties, and which is composed of positive and negative electricities. The various actions of friction, chemical action, etc. (N. 323, 324), decompose this *neutral electric fluid* into its constituent fluids. Thus, when a glass rod is rubbed with silk the neutral fluid is decomposed, positive electricity appears upon the glass, and negative electricity upon the silk. It is easy to prove experimentally (by an application of the law described N. 331) that silk which has been used as a rubber for glass possesses the same electricity as sealing-wax rubbed with flannel; while flannel which has been used as a rubber for sealing-wax possesses the same electricity as glass rubbed with silk. (N. 330.)

335. The kind of electricity developed by any

action which causes electrical separation depends upon many causes, such as temperature, structure, and physical aggregation. Thus polished glass gives positive electricity with a silk rubber, and roughened glass negative electricity with the same rubber. Again, if two similar substances possessing different temperatures be rubbed together, the cooler of the two becomes negatively electrified. (Compare N. 323.)

336. Electricity resides on the surface of bodies. If a hollow metallic cylinder be insulated (N. 328) and charged with electricity, no electricity will be found inside the cylinder. Again, a sphere of non-conducting shell-lac coated with gold leaf $\frac{1}{282,000}$ of an inch in thickness, will receive as large a charge of electricity as a solid metallic sphere of the same dimensions.

337. Electricity is evenly distributed on the surface of a sphere; that is to say, the *electric sea*, if we may so express it, possesses the same depth at every part of the surface of the sphere. Or we may otherwise express it by saying that the *electric density* or *tension* is the same at every part. On a cone the depth of the sea increases as we pass from the base to the apex, and at the apex is considerable. On an ellipsoid the sea tends to deepen as we approach the ends; and the depth of the fluid at the extremities of the major axis of the ellipsoid is greater than the depth at the extremity of the minor axis in the ratio of the major axis to the minor axis.

338. The *electric density* or *tension* at any part of the surface of a body may be defined as the amount of electricity existing on any unit area of that part. The term *tension* is also sometimes used to designate

the tendency to escape, or to effect discharge, which the electricity on a body may possess. (*Tendo*, to stretch, strain).

339. The density of electricity increases at edges, corners, and projections. At a point the density is enormously increased, and at a mathematical point it would be infinite.

340. If a conductor furnished with a sharp point be charged with electricity, the tension is so great at the point that the electricity discharges itself into the air, and the repulsion of the electrified air from the point (N. 331) produces the electrical *aura* or wind.

341. If an insulated conductor be charged with electricity, it quickly loses its charge unless special precautions are taken. The loss is due to three causes :—(α) imperfection of the insulating support; (β) conductivity of the air; (γ) electrical convection. —(*Dissipation of Electricity.*)

342. The division of bodies into conductors and non-conductors (N. 326) is not absolutely exact. The best conductor offers some resistance to the passage of electricity along it, and the best insulator permits a certain amount of electricity to pass. Again, copper and water are both classed among the conductors, but the latter offers several million times the resistance of the former. When a charged body is insulated (α, N. 341), a certain amount of its electricity escapes by the support.

343. Although perfectly dry air does not conduct electricity, moist air conducts somewhat freely, and air is never free from moisture. Hence (β, N. 341) part of the electricity of an insulated charged body is

thus conducted away. We understand also why electrical effects are best manifested on a dry frosty day.

344. We have already (N. 257) defined the *convection of heat* as the transference of heat by moving masses of liquid or gas, which are caused to ascend in opposition to the force of gravity, by the fact of their being specifically lighter than the surrounding medium. The *convection of electricity* is a somewhat analogous action. A layer of moist air in contact with a charged conductor becomes electrified, and is then repelled (N. 331), carrying with it a certain amount of the electricity of the conductor. Particles of dust are similarly attracted to a conductor, and then repelled, thus becoming carriers of electricity from the conductor; hence the loss alluded to in N. 341 (γ).

345. If a charged insulated conductor, *A*, be approximated to an uncharged insulated conductor *B*, the latter is found to exhibit evidence of electrical separation. That part of *A* which is nearest to *B* will possess the opposite kind of electricity, while that part which is remote from *A* will possess the same kind of electricity as *A*. This is called *Electrical Induction*, or more correctly *Electro-static Induction* (comp. N. 291).

346. The effect is temporary; it lasts only so long as the charged conductor is in the presence of the uncharged conductor. In fact, the electricity of the former has decomposed the neutral fluid of the latter (N. 334), attracting the fluid which is dissimilar to itself, and repelling the fluid which is similar to itself, in accordance with the known law (Notes 329, 331).

347. Let us place a conductor *A* charged with (say)

positive electricity near an insulated cylindrical conductor *B*. The negative electricity of *B* will be drawn to the end nearest the charged conductor *A*, and will be held there by the attraction of the positive electricity, in a *disguised*, or *dissimulated* condition. In fact, it will not be free electricity, for we may touch the very surface opposite *A* without removing any of the induced negative electricity. The positive electricity of *B*, is, however, free, and if we touch any part of the surface of *B*, the free positive fluid escapes to the ground. On now removing the inducing conductor *A*, the captive negative electricity of *B* is released, and *B* remains charged with free negative fluid. This is called *charging by induction.*

348. Induction takes place through a non-conducting body intervening between the charged body and the body acted upon inductively, and this medium, although generally air, may be glass, shell-lac, sulphur, or other non-conducting substance. Such medium through which electrostatic induction takes place is sometimes termed a *dielectric* (*διά*, through).

349. It may be experimentally proved that the amount of electricity induced by an electrified body on surrounding conductors is equal to that of the inducing body. We already know that the electricity induced must be opposite in kind to that of the inducing body. (Notes 345, 346.)

350. According to Faraday, induction is an action of contiguous particles. It takes place not only *through*, but *by means of* the particles of the intervening dielectric. (N. 348.) These particles are polarised (N. 287); if the inducing body be positively charged, the particles of dielectric between it and the body acted upon

inductively, each possess polar qualities, negative electricity being accumulated on the side nearest to the inducing body, and positive electricity on the side remote from the inducing body, as in the case of a single conductor. (N. 345.)

351. Under these circumstances we might reasonably assume that the particles of some dielectrics will be thrown into the polar condition more readily than those of others. In other words, that induction will take place more readily through some substances than through others. This Faraday found to be the case.

352. *Specific Inductive Capacity* signifies the capacity which a dielectric possesses of transmitting inductive influence through it; or otherwise the readiness with which the particles submit to polarisation. (N. 350.) If air be taken as unity, the specific inductive capacity of resin was found to be 1·75; glass, 1·90; shell-lac, 2·00; and sulphur, 2·24. Thus induction takes place more than twice as readily through sulphur than through a layer of air of the same thickness; and twice as much electricity would be induced in an insulated conductor separated from the inducing body by a plate of sulphur, than if a layer of air of the same thickness intervened.

353. The specific inductive capacity of all gases is the same, and is uninfluenced by temperature and pressure. (Comp. N. 229.)

354. The particles of dielectrics are conductors insulated from each other, and thus cannot suffer discharge by contact. For this reason dielectrics are non-conductors. (N. 326.)

355. The particles of conductors (N. 326) are

equally capable of polarisation, but they are imperfectly insulated from each other, and hence readily suffer discharge, the positive electricity of one particle uniting with the negative of the next, and so on throughout the conducting mass.

356. Thus conduction becomes the propagation of electricity through a mass by the mutual discharge of contiguous particles. The particles are first acted upon inductively and polarised, and then rapidly depolarised by discharge.

357. The particles of conductors are easily polarised, and easily discharge; while the particles of non-conductors are with difficulty polarised, and do not discharge. We may remember a somewhat similar action in the case of magnetism (N. 288). A soft iron bar is easily magnetised when in contact with a magnet, but it loses its magnetism as soon as the magnet is withdrawn; on the other hand, a steel bar is less easily magnetised, but retains its magnetism permanently.

358. Inductive action is very general in the case of electrical phenomena. The simplest electrical manifestation is preceded by it. Thus, although we have stated that electricity attracts light bodies (N. 329), we must, now that we understand induction, qualify our expression, and say that electricity does not directly attract light bodies, but it attracts the opposite electricity to its own (N. 331). Induction precedes attraction. If we hold a rubbed glass rod near a suspended pith ball, the latter is acted upon inductively, its neutral fluid is decomposed (N. 334), the negative is drawn to the side nearest the glass rod, and as attraction takes place between opposite fluids, the whole pith ball is attracted to the glass rod.

359. An *electrical machine* is an instrument for readily and rapidly effecting the separation of the neutral electric fluid into its constituents.

360. The first electrical machine was invented by Otto von Guericke of Magdeburgh, in 1671, and consisted of a sphere of sulphur, which was caused to rapidly rotate by machinery, and was rubbed by the hand.

361. The machine now generally used consists of three parts:—(α) a disc of glass which is caused to rotate in a vertical plane about its geometrical centre; (β) fixed rubbers which press against the disc; and (γ) an insulated conductor called the *prime conductor*, furnished with rows of points which approach near to

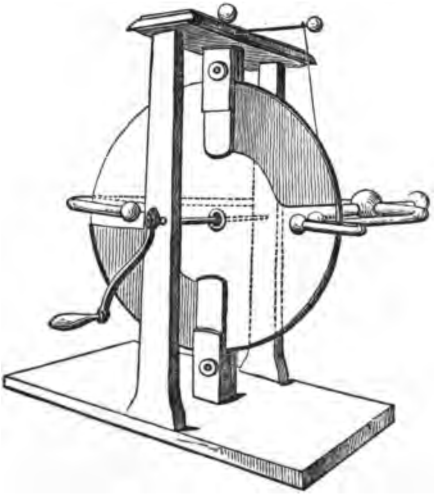


Fig. 39.

the surface of the disc, just below the rubbers. (Fig. 39.) On turning the disc, electrical separation takes place, positive electricity appears on the disc; negative (which escapes to the earth) on the rubbers. The positive electricity decomposes the neutral fluid of the prime conductor by induction (N. 345), attracting negative electricity to the points, and repelling positive electricity to the remote parts of the conductor. But the tension or density of electricity at a point is great (N. 339, 340), and the fluid accumulates to such an extent that it escapes from the points. Thus we have a stream of negative electricity rushing out from the prime conductor, and neutralising the positive electricity of the disc, and the conductor is left positively charged by induction.

362. The friction of a liquid and a solid, or of a solid and a vapour, may also effect electrical separation, and be utilised for the acquirement of static electricity. In Sir W. Armstrong's *hydroelectric machine* large quantities of electricity are produced by the friction of high-pressure steam, carrying water particles in suspension, against the sides of tortuous exit-tubes.

363. If the hand or other conducting body be held near the prime conductor of an electrical machine, a bright spark is seen. The hand is acted upon inductively, its neutral fluid is decomposed, and a quantity of negative electricity is heaped up upon it opposite to a corresponding quantity of positive electricity on the prime conductor; when the tension of these opposite electricities becomes great, their tendency to combine enables them to overcome the resistance of the air, and they combine with the production of heat, light, and sound. (*Disruptive discharge.*)

364. Let us, side by side with the electrical machine, place a windlass connected by a cord with a pulley, so as to enable us to raise a weight. If we attach the cord to a weight resting upon the earth, and turn the windlass, the weight is raised in opposition to the force of gravity. In fact, we have converted kinetic energy into potential energy (N. 104, 105), and the weight is now in a condition of potential energy because it can descend to the earth, and thus do work. Now the electrical machine obviously also enables us to convert kinetic energy into potential energy; for by it we separate the dissimilar electric fluids in opposition to their mutual attraction. We confer potential energy upon them because we place them in a position of advantage with regard to their own attractive force, and allow them the possibility of rushing together again and combining.

365. The kinetic energy expended in the production of electrical separation appears in the electric spark transformed, under the threefold actions of heat, light, and sound.

366. The duration of the electric spark has been calculated to be less than $\frac{1}{24000}$ part of a second.

367. The *Electrophorus* (φέρω, to bear) is an instrument by means of which free electricity, developed on a non-conducting substance, may be caused to decompose by induction (N. 345) the neutral fluid of an insulated conductor for an almost indefinite number of times. It was invented by Volta in 1775, and by him called *electrophoro perpetuo*, in reference to the persistence of its action.

368. The instrument consists of a cake of resin, and a somewhat smaller metallic plate fitted with an

insulating handle. The resinous cake is rubbed with fur or flannel, and becomes negatively electrified; the metal plate is then placed upon it. Now, if the metal plate came into complete contact with the charged resinous surface, it would receive negative electricity by direct communication, but owing to the minute asperities on the surface of the resin, and the fact of its not being absolutely plane, the metal plate actually touches it at a very few points. Thus the metal is acted upon inductively, its neutral fluid is decomposed, the positive electricity is drawn to the under side of the plate nearest to the resinous cake, and is there held captive, in a bound, dissimulated, latent, condition (N. 347); while the negative electricity is repelled to the upper surface of the plate, and remains there in a free state. If the metal plate be now raised, the decomposed electricities recombine, and the plate returns to its neutral condition (N. 346). But if, before raising the plate, it be touched by the hand or other conducting body in communication with the earth, the free negative electricity flows away, and on raising the plate the liberated positive electricity spreads over the surface, and the plate remains positively charged. The plate may be discharged and returned to the resinous cake, touched, raised, discharged, and so on, for a number of times; for since the resinous cake only

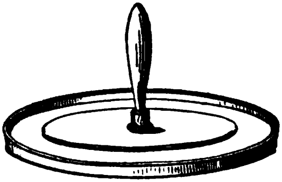


Fig. 40.

acts inductively it loses none of its electricity, and does not require fresh excitation. A cake of excited resin or ebonite will retain its electricity for several weeks in dry weather.

369. Hitherto we have not attempted to accumulate or condense electricity. That such accumulation is possible was discovered in 1745, and the instrument by which it is effected is called the *Leyden Jar.*

370. A Leyden jar consists of two conductors, separated from each other by means of a non-conductor; it usually takes the form of a glass bottle lined inside and out with tinfoil, to within a few inches of the top. The mouth of the bottle is closed by a wooden stopper, through which passes a brass rod terminated above by a knob and below by a piece of chain. The knob rises a few inches above the mouth of the bottle, and the chain is in contact with the tinfoil inside the bottle. If the knob be placed in connection with the prime conductor (N. 361) of the machine, positive electricity is communicated to the tinfoil inside the jar, this acts inductively through the

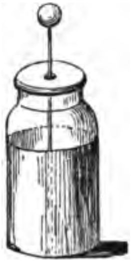


Fig. 41.

glass (N. 348), decomposing the neutral fluid of the outside tinfoil, attracting its negative fluid, which it renders latent, while the free positive electricity escapes to the earth. Thus we have a charge of positive electricity on the inside of the jar, a series of polarised particles of glass, with all their negative hemispheres, turned towards the inside coating (N. 350); and a charge of negative electricity on the outside, equal to the positive electricity within (N. 349). The two mutually attractive fluids (N. 331), separated from each other by the non-conducting glass, hold each other captive, and become dissimulated, so that the inside tinfoil is free to receive another charge of positive electricity from the prime conductor, and this becomes latent by attracting another charge of negative to the outside. This continues until we have considerable electrical density or tension (N. 338) in the jar, and the particles of glass are intensely polarised. If now the outside and inside coatings be connected, the two electricities unite with considerable violence, the particles of glass are depolarised, and the jar returns to its normal neutral condition.

371. It is easy to prove that the charge resides in the glass, not in the coatings. Thus, if we charge a jar with movable coatings, the latter may be removed and discharged, and then returned to their ordinary position. On connecting together the inside and outside coatings the glass is now discharged.

372. The coatings of the jar connect together the particles of non-conducting glass, and also serve to convey electricity to all parts of the coated surface of the jar, and to facilitate the depolarisation of the whole extent of glass when the inside and outside coatings are connected.

373. The amount of electricity which can be accumulated by a Leyden jar depends upon four causes: (α) the tension (N. 338) of electricity on the prime conductor by which the jar is charged; (β) the extent of coated surface; (γ) the thickness of the intervening dielectric (N. 348); and (δ) the specific inductive capacity (N. 352) of the intervening dielectric.

374. The degree of charge is mainly limited by the tension of the electricity on the prime conductor, and by the tendency of the two fluids to combine. As no substance is a perfect non-conductor of electricity (N. 342), a point is at length reached beyond which the glass or other intervening non-conductor refuses to be polarised. When the attraction of the separated electricities for each other exceeds the resistance offered by the non-conducting medium, the fluids combine through it, and sudden depolarisation of the particles ensues.

375. Various effects may be produced by electricity accumulated by means of the Leyden jar. Thus, if a number of persons join hands, and the last at one end of the line touches the outside coating, and the last at the other end of the line touches the inside coating, a discharge takes place through the arms and chest of each individual. This is the so-called *electric shock.* When the contact is completed, positive electricity starts from the inside of the jar, and negative from the outside at the same instant, and they meet in the centre of the circuit—that is to say, the person in the centre of the line receives the shock after the persons at the ends. We have here electricity in motion—viz. an *electric current.*

376. Thin metallic wires may be melted, and gun-

powder inflamed, by the accumulated electricity of a Leyden jar. Wood may be split, glass broken, and the various effects of lightning may be imitated on a small scale.

377. If a steel needle be placed in the centre of a helix of copper wire, and a charge from a Leyden jar be sent through the helix, the needle is converted into a magnet.

378. Thus electricity may be transformed into any, and all, of the actions which we have previously examined. For a restrained pith ball in proximity to a charged conductor is in a condition of *potential energy* (N. 104); the same pith ball if released exchanges its potential energy for *kinetic energy* (N. 105); *heat* and *light* accompany disruptive discharge (N. 363); and magnetism is produced by causing an electric current (N. 375) to circulate around a piece of iron (N. 377).

379. If an uninsulated conductor, *A*, be acted upon inductively by a (say positively) charged body, *B*, its neutral fluid will be decomposed (N. 345), the negative electricity will be attracted as near as possible to the inducing body, while the free positive will escape to the earth. If now the charged body, *B*, is discharged, the inductive action upon *A* suddenly ceases, and positive electricity runs up from the earth to combine with the liberated negative electricity of *A*. This is called the *return shock*. Gunpowder may be ignited by the return shock; and by it a man may be killed without being struck by lightning.

380. In 1752 Franklin proved the identity of lightning and electricity.

381. Atmospheric electricity is probably chiefly produced by evaporation.

382. Lightning is a disruptive discharge (N. 363) of electricity between two clouds charged with opposite electricities, or between a charged cloud and an unelectrified cloud, or between a charged cloud and the earth.

383. If lightning strikes a good conductor of electricity it passes freely to the ground; hence the efficacy of the so-called *lightning conductors.* If, on the other hand, it encounters bodies which offer resistance to its passage, such as trees, church-steeples, etc., it shatters them. The effects may be perfectly imitated by means of a Leyden jar (N. 376).

Experimental Illustration of Static Electricity.

Static Electricity may be very completely illustrated. The most indispensable pieces of apparatus are :—(α) an electrical machine, preferably a plate machine 2 or 3 feet in diameter; (β) a battery of about eight Leyden jars; each jar to have a capacity of three or four pints; (γ) a gold-leaf electroscope with carefully insulated leaves, 3 or 3½ inches long and 1 inch broad. Several insulating stands; rods of sealing wax and glass; a discharging rod; a universal discharger; and most of the pieces of apparatus usually supplied with electrical machines will be found useful adjuncts. Several insulated metal conductors will be necessary for explaining induction, also proof planes. The latter may be conveniently constructed of discs of cardboard covered with gilt paper, and insulated by a handle of ebonite, shell-lac, or glass covered with shell-lac. The discs may be of four sizes—viz. 3, 2½, 2, and 1 inch diameter respectively; they are easily fastened to their handles by means of melted shell-lac. The handles should be 9 or 10 inches long. All glass supports, and exposed glass surfaces of Leyden jars, should be coated with a thin layer of shell-lac dissolved in alcohol. A cylindrical rod of caoutchouc, about 18 inches long, and capable of balancing and turning upon a point, will be found useful for illustrating the differences between the two kinds of electricity. A disc of thin glass 15 inches diameter, and two insulated discs of brass plate 10 inches diameter, will be found of service for illustrating the principle of the Leyden jar. Such an arrangement can easily be made by the joint efforts of a plumber and a brassworker, as indeed may many pieces of electrical apparatus, which the student will soon learn to devise. Discs of shell-lac and other dielectrics are requisite for explaining Faraday's theory of induction; they should be about 6 inches in diameter, and ¼ of an inch thick. An electrophorus may be easily made; the resinous plate may be composed of equal parts of shell-lac, resin, and Venice turpentine, melted together and poured into a tin mould 12 or 15 inches diameter and ½ an inch deep.

DYNAMIC OR CURRENT ELECTRICITY.

384. Electricity developed by friction is called *static* electricity, because it remains on the surface upon which it has been developed. (*στάω*, to stand, remain; *ἵστημι*.) Thus if we rub a glass rod, the developed positive electricity remains upon it, until it comes into contact with a conductor. We have seen, however (N. 375), that when the inside and outside of a charged Leyden jar are connected, a *current* of electricity flows from one coating to the other. We have now to deal with *electricity in motion.*

385. This form of electricity is sometimes called *galvanic electricity*, *galvanism*, or *voltaic electricity*, from the names of early investigators of its nature; sometimes *dynamic electricity* (*δύναμις*, force); *kinetic electricity* (*κίνησις*, motion); or *current electricity* (*curro*, to run, move quickly).

386. The science dates from the year 1786, when Galvani, Professor of Anatomy in Pisa, noticed a peculiar convulsive action in some frogs' legs which were placed near an electrical machine, and which contracted when a spark was taken from the machine. This was due to the *return shock* (N. 379).

387. Galvani afterwards found that frogs' legs contracted when the lumbar nerve was connected with the muscle of the leg by means of dissimilar metals; and he was led to compare the legs to a self-supplying Leyden jar, one electricity of which resided in the

nerve, the other in the muscle. He further imagined that the union of the two electricities produced the convulsive action, for the same reason that a strong shock agitates the receiver of it, and he inferred that all animals have electricity in them. (*Theory of Animal Electricity.*)

388. Among the more eminent investigators who were led to examine minutely the discovery of Galvani, was Volta, Professor of Natural Philosophy at Pavia. His experiments on the subject induced him to deny the truth of the theory of animal electricity (N. 387) of Galvani, and to attribute the observed effects to electrical separation taking place at the point of contact of the dissimilar metals; the separated electricities being conducted from one part of the arrangement to another by the frog's legs. (*Contact Theory.*)

389. Acting on this belief, Volta constructed his celebrated "Pile" in 1800. This consisted of discs of dissimilar metals (zinc and copper) in contact, each pair being separated by a piece of cloth dipped in water, or in salt and water. Thus, beginning at the bottom with a copper plate, the order would be

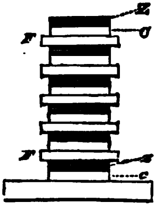


Fig. 42.

copper, zinc, cloth (C Z F, Fig. 42), copper, zinc, cloth, and so on, the terminal plate above being of zinc. (*Voltaic Pile.*)

390. By "*dissimilar* metals" (N. 389) is meant any two metals which are differently acted upon chemically by the same agent. Thus iron and gold are dissimilar, because iron oxidises with facility, while gold does not oxidise at all; again, zinc and platinum are dissimilar metals, because the former is easily dissolved by almost any acid, while the latter is unaffected by acids.

391. The zinc in Volta's pile was found to be oxidised, and this suggested to Sir Humphry Davy the idea that the electricity may be produced by chemical action, and that the combination of the oxygen with the most oxidisable metal (the zinc) is the true cause of electrical separation in the Pile. (*Chemical Theory.*)

392. The copper end of such a pile is found to be charged with positive electricity, the zinc end with negative electricity. When these ends (or *poles*, as they are called from the analogy to magnetic poles, see N. 279) are connected by means of a wire, the opposite electricities flow together, as in the somewhat analogous instance of a Leyden jar (N. 370).

393. Whenever chemical action takes place, electricity is produced. Thus, when a metal (say zinc) is acted upon by an acid (say sulphuric acid), the metal becomes charged with negative electricity, the liquid with positive electricity. The object of the non-oxidisable metal in any voltaic arrangement is to collect the positive electricity from the liquid.

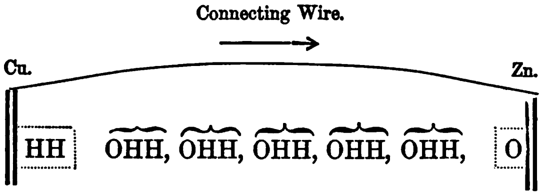
394. If two plates of dissimilar metal (N. 390), such as zinc and copper, be plunged into a liquid which acts upon one of them, such as water, or acid, no change is apparent, until the plates are connected, when hydrogen gas is seen to rise from the surface of the copper plate, while the zinc is oxidised; at the same time an *electric current* circulates through the wire connecting the plates.

395. According to the *Hypothesis of Grotthüs*, the zinc plate, before connection with the copper plate, acquires a feeble charge of negative electricity on account of its attraction for the oxygen, while the copper plate receives from the water a feeble charge of positive electricity. And the intervening molecules of water (H O) are polarised; that is, all their hydrogen atoms are turned towards the copper, and all their oxygen atoms towards the zinc. Thus the disposition of one row of atoms will be this:—

Copper. Zinc.

$$\Bigg\| \overbrace{\mathrm{HHO}}, \overbrace{\mathrm{HHO}}, \overbrace{\mathrm{HHO}}, \overbrace{\mathrm{HHO}}, \overbrace{\mathrm{HHO}}, \overbrace{\mathrm{HHO}} \Bigg\|$$

When the zinc and copper are connected, the opposite electricities flow together, the state of tension which produces the polarisation of the intervening liquid ceases, the atom of oxygen is assimilated by the zinc, and forms oxide of zinc (ZnO); the two liberated particles of hydrogen decompose the next molecule of water, robbing it of its oxygen, and so throughout the whole chain of atoms; the two final atoms of hydrogen are liberated from the copper plate. Thus, after completing the circuit, the following will be the arrangement:—



396. The current is continuous. So long as the plates are connected together, so long does electricity pass along the wire. The act of connecting the plates does indeed cause the union of the opposite electricities, and thus momentarily discharges the system; but the chemical action between the zinc and the liquid continues, and we thus obtain a continuous source of electrical separation, and a constant succession of electrical discharges through the wire. These follow each other with such rapidity that a practically continuous current is the result.

397. *Electromotive force* is the effort or force by which the current is set in motion, or urged forward on its course.

398. *Ohm's Law* in its simplest forms asserts that the strength of an electrical current (S) is equal to the Electromotive Force (E) divided by the Resistance (R); that is—

$$S = \frac{E}{R} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad 1$$

But the resistance is of two kinds, for there is the resistance within the battery (R), and the resistance of the conducting wire or other conductor outside the battery (r); thus:—

$$S = \frac{E}{R + r} \quad . \; . \; . \; . \; . \; . \; . \; 2$$

The resistance (r) of the outside conductor depends upon the diameter, length, and material of the conducting medium.

399. By the *direction of an electric current* we understand the direction in which the positive electricity flows.

400. Thus in the simple copper-zinc arrangement

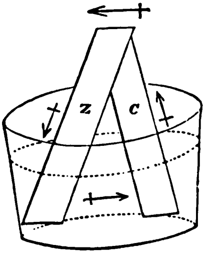


Fig. 43.

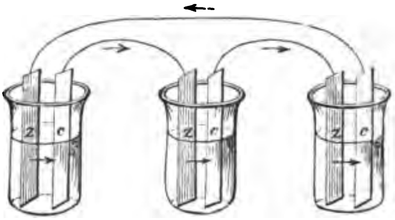


Fig. 44.

(N. 394) the direction of the current is from copper to zinc *outside* the liquid, and from zinc to copper within the liquid. Or in any of the more usual forms of constant battery employed (N. 403) from copper, platinum, or carbon, as the case may be, to zinc, outside the liquid.

401. Batteries with one liquid, such as copper and zinc placed in dilute sulphuric acid, quickly lose their strength. This is mainly due to a deposit of hydrogen gas on the copper plate, which hydrogen, on account of its chemical attraction for oxygen, tends to set up a counter-current by attracting the oxygen away from the zinc plate to which it naturally tends (N. 395). Such batteries were used, however, for thirty-six years after the invention of the Voltaic pile.

402. To obviate this loss of strength, *constant batteries* were invented. The principle of these is the use of two liquids, one of which arrests the hydrogen on its way to the positive plate (N. 395).

403. The most usual forms of constant battery are those of Daniell, Grove, and Bunsen. In Daniell's battery the metals are copper and zinc, the liquids

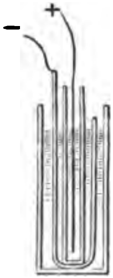
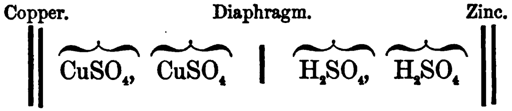


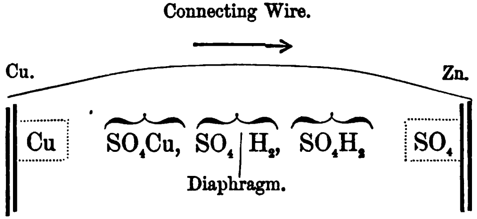
Fig. 45.

sulphate of copper and dilute sulphuric acid. In Grove's battery (Fig. 45) the metals are platinum and zinc, and the liquids strong nitric acid and dilute sulphuric acid. Bunsen's battery closely resembles Grove's, but the platinum is replaced by hard gas-retort carbon. In each form of battery the liquids are separated by a cell or diaphragm of porous unglazed earthenware.

404. The rationale of Daniell's battery is as follows (compare N. 395):—The sulphuric acid (H_2SO_4) acts upon the zinc forming sulphate of zinc ($ZnSO_4$), the liberated hydrogen decomposes a molecule of sulphate of copper ($CuSO_4$), forming sulphuric acid, and liberating copper (Cu). Thus before completing the circuit the disposition will be as follows :—



and after completing the circuit :—



405. Static electricity and current electricity are thus related to each other. In the case of the former there is small quantity, but great tension (N. 406): in the case of the latter there is great quantity, but little tension. A very powerful Voltaic battery will not give so long a spark as a rubbed glass rod ; on

the other hand, the electricity produced by the action of a few drops of water on a few grains of zinc, exceeds in quantity the electricity of a thunderstorm. We may compare the two forms of electric force to a mountain torrent, and the lake into which it falls; in the one, there is far greater moving power, but infinitely less quantity; in the other, there is far greater quantity, but infinitely less moving power.

406. The *tension*, or power of overcoming resistance, of an electric current is practically the same as the electromotive force (N. 397), and depends upon the degree of chemical affinity existing between the most oxidisable metal and the liquid of the battery (N. 391). The *quantity* of electricity generated depends, on the other hand, on the extent of surface exposed by the most oxidisable metal in the battery.

407. A wire conveying an electric current (N. 392, 394) produces certain remarkable effects, in consequence of the transformation of the current (or, otherwise expressed, of the energy of electricity in motion) into other forms of energy. These effects may be classed as (α) physiological; (β) thermal; (γ) luminous; (δ) chemical; (ϵ) magnetical.

408. We have already seen (No. 375) that when the re-composition of the separated electric fluids is allowed to take place through the arms and chest, an *electric shock* is felt. If the opposite ends of a powerful Voltaic battery are simultaneously touched by the hands the same effect is produced. A very weak current, if applied to opposite portions of a dead frog, produces violent contractions in the limbs. (Compare N. 386). A strong current, if applied to various exposed nerves and muscles of any animal shortly

after death, produces muscular actions similar to those exercised during life: the limbs move, the eyeballs roll, the chest is elevated and depressed with regularity.

409. We already know that electricity in motion may be transformed into heat (N. 218). If the *poles* of a Voltaic battery (N. 392) are joined by a thin wire of badly conducting substance, such as platinum, heat is produced. The amount of heat is proportional to the resistance of the conductor, and to the square of the intensity of the current. The heat produced by a powerful battery is considerable: copper and platinum melt in a Voltaic arc (N. 410) like wax in a candle-flame, and are volatilised.

410. If the wires connecting the poles of a powerful battery are furnished with terminations of hard carbon, and are then brought into contact, the carbon glows with a white heat, and becomes intensely luminous; if the carbon points are then separated to a slight distance (depending on the power of the battery), an arc of brilliant flame will pass between them. This is called the *Voltaic arc.* It furnishes at the same time the most intense heat, and the most intense light, which we can by any means procure. The light possesses more than one-third of the intensity of solar light. A Voltaic arc extending between charcoal points only a quarter of an inch apart, was found to emit light equal to that of 572 candles.

411. If the wires connecting the poles of a Voltaic battery are immersed in water, the latter is decomposed into its constituent gases; the oxygen being given off at the positive pole, or where the current *enters* the liquid (see N. 399), and the hydrogen at

the negative pole. Various compound substances may be decomposed by an electric current; it was thus that Sir Humphry Davy discovered potassium and sodium in 1807.

412. The elements which are liberated at the positive pole of the battery are termed *electro-negative*, while those that are liberated at the negative pole are termed *electro-positive.* Thus oxygen is electro-negative, and hydrogen electro-positive.

413. The constituents of the decomposed body only appear at the poles; thus, it is believed, that decomposition takes place in accordance with the hypothesis of Grotthüs, and that hence the particles of the decomposed body between the poles are thrown into a polarised condition, as shown in the case of water in N. 395.

414. The operation of decomposing by current electricity is termed *electrolysis* (λύω, to loosen), and the body decomposed, an *electrolyte.*

415. In 1819 Oersted, of Copenhagen, discovered that an intimate relationship exists between electricity in motion and magnetism. He found that if a wire conveying an electric current be placed parallel

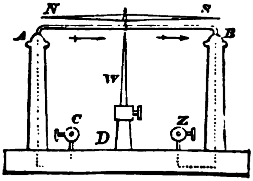


Fig. 46.

to a freely suspended magnetic needle (N. 280) and above or below it, the needle is deflected from the north and south position which the magnetism of the earth causes it to assume (N. 298), and tends to set itself at right angles to the direction of the current.

416. A wire, say of copper, is itself magnetic while it conveys an electric current, and is capable of attracting iron-filings. If the wire be insulated by surrounding it with cotton, and then wound round an iron bar, the latter becomes powerfully magnetic so long as the current circulates round it.

417. A bar of soft iron wire, which is thus temporarily converted into a magnet (N. 289) by the action of an electric current, is called an *electro-magnet.* That branch of electricity which treats of the magnetical relationships of current electricity is called *electro-magnetism.*

418. A magnetic needle is deflected in a certain direction by an electrical current; thus, if the current be above the needle, and passes from south to north, the north pole of the needle is deflected to the west. Or, more generally expressed, we may ascertain the direction of deflection under any circumstances (and conversely the direction of the current by noticing the deflection), by the following means:—Let us bear in mind that the direction of the current is assumed to be the direction in which the positive electricity flows (N. 399); then if the observer imagines himself to be swimming in, and with, the current, and to have his face turned towards the needle, the north end of the needle will always be deflected to his left hand.

419. *Galvanometers* are instruments for measuring

the intensity of an electric current. They are of various forms, and depend on the deflection of a magnetic needle by a current.

420. If several magnetic needles be placed under a continuous copper wire, and if the wire be caused to convey an electric current, all the needles are deflected at once, and in the same direction, although they may be miles apart. Then, by varying the direction of the current, the needles may be deflected to right or left at will (N. 418); hence an extensive system of signalling becomes possible. This is the principle of the *Electric Telegraph.*

421. Electric currents affect each other: thus it may be proved by means of movable wires which can be traversed by an electric current:—(α) that two parallel currents, which move in the same direction, attract each other; (β) that two parallel currents, which move in opposite directions, repel each other.

422. A freely suspended magnetic needle tends to set itself at right angles to a proximate electric current (N. 415). Similarly a movable current sets itself at right angles to a stationary magnet.

423. If we arrange a number of electric currents at right angles to a common axis, it is obvious that the arrangement will behave like a common magnet, and the axis, if free to move, will take up a position in the magnetic meridian.

424. Such a result may be easily effected by transmitting an electric current through a movable wire helix. The latter is called a *solenoid* (σωλήν, a tube).

425. A solenoid conveying an electric current be-

haves exactly like a magnet; it sets itself in the magnetic meridian, it possesses a north and south pole, and consequently it is attracted and repelled by another solenoid, or by a permanent magnet, or electro-magnet, in accordance with the law before enunciated (N. 282).

426. The action of a solenoid suggested *Ampère's theory of magnetism*, which assumes that a magnet is a solenoid, around each atom of which an electric current circulates. Within the mass of the magnet, these currents neutralise each other, because the currents are in opposite directions, and the ultimate effect is as if currents were circulating around the exterior of the magnet (Fig. 47), as in the solenoid.

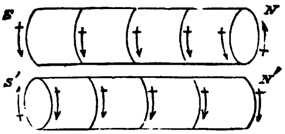


Fig. 47.

427. If a wire conveying an electric current be rapidly approximated to a conducting wire, a current is induced in the latter, moving in an opposite direction to that of the inducing current; and if a wire conveying a current be rapidly withdrawn from the presence of a conducting wire, a current is induced in the reverse direction—viz. in the same direction as that of the inducing current. (*Induced currents.*)

428. Again, if a conducting wire be caused to approach or recede from a magnet, a current of electricity is induced. (*Magneto-electric induction.*)

429. If two different metals, or the same metal in a different state of physical aggregation, be joined at one point, and if the juncture be heated, or cooled, an electric current is produced. (*Thermo-electricity.*)

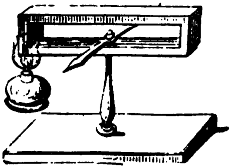


Fig. 48.

Thus, if a rectangle (Fig. 48) be formed of antimony and bismuth, and a magnetic needle be suspended within it, the needle will be deflected on heating one of the junctions of the two metals.

Experimental Illustration of Dynamic Electricity.

A battery of twelve quart Bunsen cells will be found sufficient for most purposes. It should be kept outside the lecture-room, and the electricity should be transmitted to the lecture-table by wires of the purest copper wire, at least one-eighth of an inch diameter, thickly coated with caoutchouc. Or a liquid battery may be altogether dispensed with (except for illustrating the different forms of battery and the electric light) by using six or eight of Noë's thermo-electric batteries of 80 pairs of elements each, but the expense of this is considerable at the outset. A fairly powerful Rhumkorff's coil may be procured from Gaiffe of Paris, for about two hundred francs. The various processes of electrolysis should be thoroughly understood by the student; different solutions should be decomposed, and the division of bodies into electro-negative and electro-positive rendered clear. Solutions of sulphate of copper, sulphate of sodium, and of iodide of potassium, are very useful for this purpose. The hypothesis of Grotthüs, and its applications to the explanation of the actions which take place in a cell of Wollaston, Daniell, and Grove, respectively, should be fully comprehended. Also the polarisation of the electrodes, and the establishment of the reverse current. Ampère's electro-dynamic experiments must be repeated, and his law committed to memory. Experiments with movable currents are not always easy of accomplishment, but by the use of clean mercury, levelling screws, and well-balanced wire rectangles and solenoids, the difficulties may be overcome. A rough vertical galvanometer is useful to show the direction in which a current is passing, the direction of deflection when the positive wire is connected with a given binding screw having been predetermined.

CONCLUSION.

We have thus together briefly examined some of the more prominent laws of Nature. You have, no doubt, observed that the tendency of modern scientific thought is to render the various sciences more and more dynamic in character. The terms *imponderables* and *imponderable fluids*, not long since used to designate the various attributes of matter, have disappeared from our text-books. Heat and light have been resolved into forms of motion, and there can be no doubt that before long electricity and magnetism will receive similar treatment. Whenever it seems expedient, we must transfer those ideas which we are wont to associate with visible masses of matter to invisible molecules of matter. We must see in our mind's eye an oscillating molecule, as readily as we see an oscillating pendulum with our bodily eye. The dash of ether waves upon the retina must present no greater obstacle to our imagination than the sight of the waves of the sea dashing upon a rock. A gaseous molecule speeding rectilineally through space must be as veritably conceived as the discharge of a cannon-ball. We must extend our perception both in the direction of the infinitely little and the infinitely great—the microcosm and the macrocosm. The grandest problems of celestial dynamics must be associated with problems of atomic dynamics. The same laws apply to both; the difference is one of degree, not of form. We know that if we disperse a solar beam into its threefold qualities —thermic, luminous, and actinic—we see a spectrum, beyond which on either side stretch other spectra which we cannot see, and can only recognise by special means. This but typifies many actions of the physical world; we recognise directly with the senses not one quarter—nay, not one hundredth part of the moods and attributes of matter. I suppose not the most fervent worshipper of the sun of old,—the prostrate Aryan watching for his first morning ray, the fervid Zoroastrian, the Sabæan contemplating the calm Chaldæan sky, the Egyptian of the nineteenth dynasty, the Greek with his *Φοῖβος Απόλλω*, rightly *φάος βιου*,—not one of these ever associated with the sun, in their wildest imaginings, one-half the qualities which sober, reasoning, science has proved that he possesses. They knew him not as the centre of the system to which the earth belongs, as the source of all our energy, as

> "The great luminary
> Aloof the vulgar constellations thick,
> That from his lordly eye keep distance due,
> Dispenses light from far; they as they move
> Their starry dance in numbers that compute
> Days, months, and years, towards his all-cheering lamp,
> Turn swift their various motions, or are turned
> By his magnetic beam, that gently warms
> The Universe, and to each inward part
> With gentle penetration, though unseen,
> Shoots invisible virtue even to the deep."

One word more: let me warn you to avoid in your study of Natural Philosophy—in all your studies—the injurious Positivism which is unfortunately beginning to take root in this country; even to be received as a welcome guest. The study of Nature, properly pursued, should not lead us to arrogate to ourselves the right of designing the Universe; of criticising the assumed *why* and *wherefore* of all things; of trying to place our pitifully finite intellects on a level with the Infinite Intellect. Humility rather befits the student of science. He may dare all things, and endure all things, in the legitimate search for truth, but he must beware of intellectual pride, and a too curious spirit; and he may fitly lay to heart the story of Pentheus,* and the interpretation of it given by one of the fathers of Natural Philosophy,—whose precepts he can never follow too closely.

---

* "Alia est Penthei calamitas. Qui enim ausu temerario, mortalitatis parum memores, per excelsa Naturæ et philosophiæ fastigia (tanquam arbore conscensa) ad mysteria divina aspirant, hiis pœna proposita est, perpetuæ inconstantiæ, et judicii vicillantis et perplexi. Cum enim aliud sit lumen Naturæ, aliud divinum, ita cum illis fit, ac si duos soles viderent. Cumque actiones vitæ, et decreta voluntatis ab intellectu pendeant: sequitur etiam ut non minus voluntate, quam opinione hæsitent, nec sibi omnino constent: itaque et duas Thebas similiter vident. Per Thebas enim actionum fines describuntur (cum Thebis Pentheo esset domus et perfugium). Hinc sit, ut nesciant, quo se vertant, sed de summa rerum incerti et fluctuantes, tantum subitis mentis impulsibus in singulis circumagantur."—FR. BACON *De Sapientia Veterum.*

INDEX.

N.B.—*The numbers refer to notes, not to pages.*

ABSORPTION OF HEAT, 269.
Accelerating force of gravity, 92.
Action, 84.
Air, 150.
    weight of, 152.
    pressure of, 156.
Air-pump, 162.
Amorphous solidification, 245.
Ampère's theory of magnetism, 426.
Angular velocity, 108.
Animal electricity, theory of, 387.
Archimedes, law of, 129.
    screw of, 146.
Arc, voltaic, 410.
Atmosphere of pressure, 157.
Atmospheric electricity, 380-383.
Atom, 284.

B

BALLOON, cause of ascent of, 161.
Barometer, 152.
    water, 155.
Batteries, constant, 402-404.
Body, rigid, 44.
Boiling-point, 240-242.
Boyle's law, 159.
Bunsen's battery, 403.
Buoyancy, 128.

C

CAMERA OBSCURA, 198.
Capacity, specific inductive, 352, 353.
Capillarity, 116.
Centre of oscillation, 101.
Charging by induction, 347.
Chemical action, production of heat by, 217.
Chemical effects of an electric current, 411 to 414.
Chemical theory, 391.
Co-efficient of expansion, 227.
Coercive force, 289.
Cohesion, 13, 14, 15.
Collision of inelastic bodies, 111
Composition of forces, 85.
    of velocities, 82.
Compressibility, 11.
Compressibility of liquids, 117.
Conduction of electricity, 356, 357.
    of heat, 256.
Conductivity of substances, 327.
Conductor, prime, 361.
Conductors, lightning, 383.
    of electricity, 326, 327, 343.
Constant batteries, 402 to 404.
Contact theory, 388.
Contraction, 221.
Convection of electricity, 344.
    of heat, 257.
Crystallization, 245.
Current, electric, 375.
Currents, induced, 427.

D

DANIELL'S BATTERY, 404.
Davy's chemical theory, 391.
Declination or deviation, magnetic, 302-306.

Decomposition by an electric current, 411.
Decomposition of light, 196.
De Magnete, treatise, 322.
Density, electric, 337, 338.
Descartes' law, 191.
Descending jet, 142.
  constitution of, 146.
Dew, 267.
Dew-point, 268.
Diamagnetism, 318.
Dielectric, 348.
Dip, magnetic, 307-309.
Dipping needle, 308.
Direction of a force, 30.
  of an electric current, 399, 400.
Discharge, disruptive, 363.
Dispersion of light, 196.
Disruptive discharge, 363.
Dissipation of electricity, 342-344.
Divisibility, 9.
Ductility, 20.
Duration of electric spark, 366.
Dynamics, 64.
Dynamic electricity, 384.

E

EBULLITION, 239.
Efflux of liquids, 134-138.
Elastic fluids, 148.
Elasticity, 21, 22.
  limit of, 21.
  of gases, 159.
Electrical induction, 345-350.
  machine, 359-362.
Electric current, 375.
  direction of, 399, 400.
  quantity of, 406.
  tension of, 406.
Electric density, 337, 338.
  fluid, neutral, 334.
  sea, 337.
  shock, 375.
  spark, duration of, 366.
  telegraph, 420.
  tension, 337, 338.
Electricity, 321.
  animal, theory of, 387.
  conductors of, 326, 327, 343.
  convection of, 344.
  dissipation of, 342-344.
  in motion, 384.
  negative, 330
  positive, 330.
  production of heat by, 218.
  sources of, 323, 324.
Electrolysis, 414.
Electro-magnet, 417.
Electro-magnetism, 415-418.
Electrometers, 333.
Electromotive force, 397.
Electro-negative elements, 412.
Electrophorus, 367, 368.
Electro-positive elements, 412.
Electroscopes, 333.
Electro-static induction, 345-350.
Ellipse, energy of a body moving in, 110.
Emission theory of light, 168.
Energy, 102-105.
  kinetic, 105.
  of a body moving in an ellipse, 110.
  of a pendulum, 106.
  potential, 104.
Equator of a magnet, 279.
Equilibrium, 56.
Equivalent, mechanical, of heat, 211.
Ether, 170.
Evaporation, 238.
  in the spheroidal condition, 243.
Eye, 199, 200.
  adjustment of, to distances, 200.
Exchanges, theory of, 264.
Expansion, 220.
  coefficient of, 227.
  linear, superficial, and cubical, 231.
  of gases, 230.
Experimental illustration of dynamic electricity, 429.
  of dynamics, 112.

Experimental illustration of heat, 273.
of hydrodynamics, 146.
of hydrostatics, 131.
of light, 200.
of magnetism, 320.
of pneumatics, 164.
of static electricity, 383.
method, 3.
Extension, 7.

F

Falling bodies, laws of, 88, 89, 90.
Faraday's theory of induction, 350.
Flexure, 24.
Fluids, elastic, 148.
Focus, principal, 186.
real and virtual, 187.
of a mirror, 186.
Footpound, 79.
Force, definition of, 28.
direction of, 30.
electromotive, 397.
magnitude of, 31.
representation of, 32.
unit of, 78.
Forces, composition of, 35.
parallelogram of, 37.
resolution of, 38.
Friction, 60.

G

Galvanometer, 419.
Gas, condensable, 149.
permanent, 149.
Gases, 148-151, 225.
condensation of, 233.
elasticity of, 159.
specific inductive capacity of, 353.
transmit pressure, 158.
Gold-leaf electroscope, 333.
Gramme, 26.
Gravity, 62.
Gravitation, universal, law of, 87.
Gravity, accelerating force of, 92.
specific, 131.
Grotthüs, hypothesis of, 395.
Grove's battery, 403.

H

Hardness, 16.
Heat, 201.
absorption of, 269.
conduction of, 256.
convection of, 257.
latent, 252, 253.
mechanical equivalent of, 211.
radiant, 258.
Heat, specific, 254, 255.
sources of, 212-214.
spectrum, 262.
unit of, 210.
Hydraulics, 132.
Hydrodynamics, 132.
Hydroelectric machine, 362.
Hydrostatic press, 119.
Hydrostatics, 113.
Hygrometer, Daniell's, 268.
Hypothesis, 285.
of Grotthüs, 395.
of two electric fluids, 334.
of two magnetic fluids, 285.

I

Illuminated Bodies, 177.
Impenetrability, 8.
Inclined plane, 55.
Inelastic bodies, collision of, 111.
Inertia, 12.
Index of refraction, 192.
Induced currents, 427.
Induction, charging by, 347.
electrical, 345-350.
magnetic, 291, 292.
magneto-electric, 428.
Inductive capacity, specific, 352, 353.
Insulation, 328.
Intensity of light, 180.
Internal work of a mass of matter, 249.
Interstellar medium, 170.
Isochronism of the pendulum, 100.
Isogonic lines, 306.
Isoclinic lines, 311.
Isodynamic lines, 316.

K

- KILOGRAMME, 31.
- Kilogrammetre, 79.
- Kinetic electricity, 385.
- Kinetic energy, 105.

L

- LATENT HEAT, 252, 258.
- Lateral action, 163.
- Law of Archimedes, 129.
  - Boyle, 159.
  - Descartes, 191.
  - Ohm, 398.
- Law of Pascal, 118.
  - Torricelli, 133.
  - universal gravitation, 87.
- Laws of falling bodies, 88, 89, 90.
  - magnetism, 282-284.
  - motion, 80, 81, 83.
  - the pendulum, 100.
- Length, unit of, 66.
- Lenses, 193.
- Lever, arms of, 50.
- Levers, 43-52.
- Leyden jar, 369-374.
  - effects of, 375-377.
- Light, 165.
  - decomposition of, 196.
  - dispersion of, 196.
  - intensity of, 180.
  - ray of, 171.
  - reflection of, 182-188.
  - refraction of, 190.
  - undulatory theory of, 169.
  - velocity of, 181.
- Lightning, 382.
  - and electricity, identity of, 380.
  - conductors, 383.
- Lines, isoglinic, 311.
  - isodynamic, 316.
  - isogonic, 306.
- Liquids, 224.
- Luminous bodies, 176.

M

- MACHINE, definition of, 39.
- Machine, electrical, 259-363.
  - hydroelectric, 362.
- Magnet, artificial, 277.
  - constitution of, 278-286.
  - natural, 277.
  - permanent, 289.
  - temporary, 289.
- Magnetisation, 276.
- Magnetism, 275.
  - Ampère's theory of, 426.
  - intensity of terrestrial, 315.
  - laws of, 282-284.
- Magnetic declination, 302-306.
  - dip, 307-309.
  - equator of the earth, 312.
  - fluids, 285.
  - induction, 291, 292.
  - meridian, 301.
  - needle, 280.
  - oxide of iron, 274.
  - poles of the earth, 310.
  - substances, 294.
- Magneto-electric induction, 428.
- Magnitude of a force, 31.
- Malleability, 19.
- Mass, 26.
- Matter, definition of, 5.
  - properties of, 6.
- Maximum density of water, 248.
- Mechanical equivalent of heat, 211
  - philosophy, 25.
  - powers, 41.
  - work, unit of, 79.
- Medium, interstellar, 170.
- Meridian, magnetic, 301.
- Meteoric theory of the sum, 273.
- Molecule, 202.
- Molecular potential energy, 250.
- Moments, principle of, 51,
- Momentum, 76.
- Motion, laws of, 80, 81, 83.
  - line of, 69.

N

- NATURAL PHILOSOPHY, definition of, 1,
- Negative electricity, 330.

Newton's law of universal gravitation, 87.
North Pole of a magnet, 281

O

OERSTED'S EXPERIMENT, 415.
Ohm's law, 398.
Opaque bodies, 179.
Oscillation, 174.
centre of, 101.

P

PARALLELOGRAM OF FORCES, 37.
Pascal's law, 118.
Path of a projectile, 96.
Pendulum, 97, 98, 99.
laws of, 100.
Philosophy, mechanical, 25.
Phlogiston, theory of, 205
Physiological effects of an electric current, 408.
Pile, Voltaic, 389.
Plane, inclined, 55.
Pneumatics, 147.
Point, action of, 339, 340.
Polarity, 287.
Poles, magnetic, of the earth, 310.
of a magnet, 279.
Porosity, 10.
Positive electricity, 330.
Potential energy, 104.
molecular, 250.
Power, 40.
Powers, mechanical, 41.
Pressure, atmosphere of, 157.
of the air, 156.
transmitted by liquids, 118-120
Prevost's theory of exchanges, 264.
Prime conductor, 361.
Prism, 194.
Projectile, path of, 96.
Properties of matter, 6.
Pulley, 59.
Pump, air, 162.
water, 163.

Q

QUANTITY of an electric current, 406.

R

RADIANT HEAT, 258.
intensity of, 263.
Ray of light, 171.
Rays, pencil, and sheaf of, 172.
Reaction, 84.
Reflection of light, 182-188.
of radiant heat, 265.
Refraction, index of, 192.
of light, 190.
of radiant heat, 266.
Resistance, 40.
electrical, 326.
Resolution of forces, 38.
Rest, 29.
Retroactive tenacity, 18.
Return shock, 379.

S

Screw, 58.
of Archimedes, 146.
Senses, fallacy of, 3.
Shock, electric, 375.
return, 379.
Siphon, 164.
Solenoid, 424.
Solids, 223.
Solidification, 244.
amorphous, 246.
Sources of heat, 212-214.
Spark, electric, duration of, 366.
Specific gravity, 131.
heat, 254, 255.
inductive capacity, 352, 353.
Spectrum, 197.
heat, 262.
Spheroidal condition, 243.
Statics, 25.
experimental illustration of, 63.
Sun, 271-273.
Surface, unit of, 66.

T

TELEGRAPH, electric, 420.
Temperature, 236.
Tenacity, 17.
    retro-active, 18.
Tension, electric, 337, 338.
Tension of an electric current, 406.
Theory, 264.
    of animal electricity, 387.
    of magnetism, 426.
    of Phlogiston, 205.
Thermal effects of an electric current, 409.
Thermo-electricity, 429.
Thermometers, 237.
Time, unit of, 67.
Torricellian vacuum, 153.
Torricelli, law of, 133.
Torsion, 23.
Transparent bodies, 178.
Two-fluid hypothesis, 334.

U

UNDULATION, 174.
Undulatory theory of light, 169.
Unit of force, 78.
    of heat, 210.
    of mechanical work, 79.
Units of length, surface, and capacity, 66.
    of time, 67.
    of velocity, 68.
Upward pressure of liquids, 127, 128.

V

VACUUM, 154.
    Torricellian, 153.
Vapour, 149.
Variation, magnetic, 302-306.
Velocities, composition of, 82.
Velocity, 71.
    acquired by a body falling down an inclined plane, 107.
    angular, 108.
    mean, 73.
    of a body projected upwards, 93, 94, 95.
    of light, 181.
    uniformly accelerated, 74.
    uniformly retarded, 75.
    variable, 72.
Velocity, unit of, 68.
Vena contracta, 138, 139.
Vibration, 174.
    of a pendulum, 100.
Voltaic arc, 410.
    electricity, 385.
    pile, 389.
Volta's contact theory, 388.
    pile, 389.
Volume, unit of, 66.

W

WATER barometer, 155.
    maximum density of, 248.
    pump, 163.
    wheels, 145.
Wave, phases of, 175.
Wedge, 57.
Weight, 27.
Wheel and axle, 54.

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